# THE APPLICATION OF AIRPHOTOS TO FOUNDATION PROBLEMS

JULY, 1956
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by
B. H. Moore


Joint Highway Research Project


PURDUE UNIVERSITY
LAFAYETTE INDIANA

THE APPLICATION OF AIRPHOTOS TO FOUNDATION PROBLEMS

To: K. B. Woods, Director
From Harold L. Michael, Assistant Director

July 26, 1956
File: 6-2-3-3
C-36-36F

Attached is a report entitled "The Application of Airphotos to Foundation Problems" by Mr. B. H. Moore. This report was prepared under the general supervision of Profs. R. D. Miles and R. E. Frost, and was also used by Mr. Moore as a thesis in partial fulfillment for the Degree of Master of Science in Civil Engineering.

This study was designed to develop procedures for the use of airphotos in predicting sub-surface soil conditions. The work was done on two different soil profiles: those essentially inorganic and those containing muck located along Indiana Toll Road where it crosses the Valparaiso Moraine in Porter and LaPorte Counties.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
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# THE APPLICATION OF AIRPHOTOS TO FOUNDATION PROBLEMS

by

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Purdue University
Lafayette, Indiana

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## ABSTRACT

Moore, Bruce Halsey, M. S. in C. E., Purdue University, August 1956. THE APPLICATION OF AIRPHOTOS TO FOUNDATION PROBLEMS. Major Professor: Robert D. Miles.

This study was designed to develop procedures for the use of airphotos in predicting sub-surface soil conditions. The procedures were developed on the Valporaiso Moraine in Porter and Laporte Counties, Indiana and are thus limited in application.

The work was done on two different soil profiles: those essentially inorganic and those containing muck.

The procedures developed for both types of materials are similar in that they both include a preliminary area study and a detailed site study. The preliminary area study in both cases used the previously developed procedures for surface soil predictions as to the general parent material of the area. The detailed site study for inorganic soils places emphasis on the elements of tone, topography, environment, and erosion. The detailed study for muck soils uses the elements of tone, erosion, environment and topography with its subdivisions of shoulders and size.

Within the morainic areas, predictions of major sub-surface soil changes; of the general constituents of the major soil changes; and of the degree of variation or presence of stratification within the major soil change were proven to be feasible. The parent material underlying a kettle, the composition of the material filling the kettle beneath the muck and the depth of muck within the kettle were also shown to be predictable within certain limits.

# CHAPTER I

# INTRODUCTION

## Purpose

The design of a foundation, be it for a bridge or a steel mill, is only as accurate as the knowledge of what soils are in the area beneath the proposed structure. For this reason, considerable time, effort and money has been spent in the development of boring equipment and procedures for the accurate determination of sub-surface soils. Boring procedures are expensive and time consuming. This thesis was undertaken to develop airphoto interpretation procedures for the rapid determination of sub-surface soils.

## Scope - Limitations

Severe limitations were instituted due to the broadness of the above stated purpose. The area studied was reduced to one example of one land form. The Valporaiso Moraine in Porter and Laporte Counties, Indiana, was chosen because of the mass of boring data available from the Indiana Toll Road Commission on this moraine. The boring program carried out by the above was inadequate for checking depths below 40 feet thus no attempt was made to predict depth to bedrock or materials beyond this arbitrary 40-foot depth. Locating bedrock in this area would be superflous in any practical investigation because of the known great depth of rock. It is the writer's opinion that physical properties of the soil, such as limits or shear strength, are not inferable from airphotos and as such no attempt was made to include such properties in the predictions.

The study was divided into two sections, one a study of the essentially inorganic soils present in the moraine, the other an examination of the muck soils of the area. The first section on the prediction of the sub-surface inorganic soils was carried out through a study of some of the sites along the route of the Indiana East-West Toll Road where clusters of borings had been made. There were eighteen sites examined in the final check of the procedure for this section. The procedure developed was designed to give the major soil changes, to give the depth at which the change occurs, and to indicate the degree of minor variations present in the sub-surface profile.

The importance and abundance of muck and peat soils in the area made a separate study of these soils feasible. This separate study was designed to determine the depth of muck and the composition of the underlying soil material. The procedure was developed using three test sites and finally evaluated by studying eighteen various size deposits. The majority of these sites were located along the route of the Toll Road in Laporte County, Indiana.

## Background

For a number of years the Joint Highway Research Project at Purdue University has been developing airphoto interpretation techniques. Pacifico Montano (17)* initiated the soil investigation techniques in northern Indiana. Merrit Davis (4) enlarged the applications introduced by Montano, but like his predecessor, did not enter into other than

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* Numbers in parenthesis refer to Bibliography

surface soils. This study will attempt to identify sub-surface soils, but will make no attempt at the engineering evaluation of these soils.

Underlying the application of airphotos to the prediction of surface soils are several basic principles. These principles are: (8)

1. The airphoto records the results of natural processes in the development of soil by reflecting surface and sub-surface features.

2. Soils can be grouped together to form a pattern which is composed of recognizable surface features.

3. Similar soils will create similar patterns where ever found while different soils will create different patterns where ever found.

The use of these principles necessitates the use of interpretive powers in evaluating soils. For more effective interpretation certain factors common to all soil patterns are used. These common factors are termed photo pattern elements. They are seven in number and are as follows:

1. Land form or topography
2. Drainage pattern
3. Erosional features
4. Photo tones
5. Vegetation
6. Cultural features
7. Special features

These elements have been adequately discussed by many authors (4, 8, 17) and will not be discussed here.

The procedure for determining surface soils consists of four steps (8). First, a literature survey is made of the area to be studied. This consists of surveying all the available geologic, pedologic and physiographical information on the site. Next, an area study approximately bounding major soil groups is made from a mosaic of the area using readily visible pattern differences. Individual photos are examined and the soil boundaries pinpointed. The pattern elements are studied and preliminary predictions as to soils are made. A field investigation is made as the third step. The concluding step is a comparison and evaluation of all the previously collected data such that a conclusion as to the soils present can be made.

The area under study, physiographically speaking, lies in the Central Lowland East of the Mississippi River and is located in the Great Lake Section of the province (5). Fenneman describes this section as follows:

> The distinguishing characteristic of the northeastern part of the Central Lowland is the dominance and variety of features of recent glacial origin. Lakes are so abundant as to characterize the region but they are very unequally distributed. Large areas are without them. Swamps, large and small, represent the intermediate stages between lakes and dry land. The number of basins, large and small, is vastly greater than is shown, even on the best maps. In addition there are marginal moraines and outwash plains, and between them large areas of rolling ground moraine. These superficial features are more or less interrelated, but all are ultimately related to an uneven rock floor in which were master valleys which cast the ice into distinct lobes. It is not only the typical assemblage of topographic forms but the group of problems largely connected with the Great Lakes that makes it desirable to treat this region by itself, although geologically its limits are arbitrary.

The portion of the Great Lake Section that appears in Indiana has been called the Northern Moraine and Lake Region (14). Fenneman's description of the Great Lakes Section aptly describes this section which has been further broken down into five units which are the Calumet Lacustrine Section, the Valporaiso Moraine Section, the Kankakee

Lacustrine Section, the Steuben Morainal Lake Section, and the Maumee Lacustrine Section (14). These sections are not confined within the borders of Indiana but extend in all cases into the surrounding state or states. This study is concerned with the Valporaiso Moraine Section.

The Valporaiso Moraine may be compared to an immense "U" surrounding Lake Michigan (13). It can be divided into two general sections on the basis of topography. The western section, beginning at approximately Valporaiso, Indiana, and extending through Indiana, Illinois and north into Wisconsin has swell and sag topography with gentle slopes. In Indiana, this western section is from 12 to 15 miles wide and is composed of three distinct but nearly merging morainic ridges. The highest point is reached in Lake County at an elevation of 750 feet. The local relief from swell to sag generally is in the range of 20 to 30 feet. The eastern section extending through Indiana northward into Michigan has rough knob and kettle topography with irregular slopes. The local relief varies considerably, being mostly in the range of 30 to 50 feet. This portion also narrows to an average width of 8 miles and the altitude increases to 855 feet at the highest knob in Laporte County. The distance to Lake Michigan decreases from 15 miles at the Indiana-Illinois border to 2 miles at the Indiana-Michigan border.

A moraine, as defined by geologists, is an accumulation of earth and rock fragments picked up, carried and finally deposited by a glacier (22). Moraines are divided into four classes according to the position and motion of the glacier at the time of their deposition. True differences in moraines for the engineer interested in soils should not be in terms of glacial position and motion, but rather in terms of structure or methods of glacial action in building the moraines. Such a genetic classification was proposed by T. C. Chamberlin in 1894 (2) but has not come into general use. He proposed four classifications of morainic structure: "dump moraine," "push moraine," "kame moraine" and "lodge moraine." A dump moraine, as the name implies, is built when the glacier quickly recedes and dumps its load in one position. Kame moraine is a modification of dump moraine in that there is considerable melt water present for the removal of the finer materials. Push moraine is that moraine where the material has been built up by the pushing and ridging action of the glacier. The term lodge moraine implies a moraine built by the lodgement beneath the ice of particles, generally of finer material, as the glacier recedes. All genetic classifications may be found in a single cross section of one moraine. Generally one process is dominant over the others and the moraine would be named in accordance with the dominant classification (2).

The Valporaiso Moraine being the focus of interest should be studied in more detail. Leverett (13) places the moraine in the Wisconsin Sub-Stage and assigns it the terminal position of this substage for the Lake Michigan Glacier. This classifies the moraine as terminal moraine marking a readvance of the ice. A wide variation in structure is present in this moraine. Starting at the Indiana-Illinois border the moraine is of the lodge type with a pebble clay till, blue in color, with a nut-like structure. In the vicinity of Valporaiso, Indiana, the moraine changes character to one of the dump or kame type composed of sand and gravel, a more porous material. This structure is generally maintained across Indiana and on into Michigan. Till can at times be found in this section but sands and gravels greatly predominate.

# CHAPTER II

# AIRPHOTO PREDICTION OF INORGANIC SUB-SURFACE SOILS

## Introduction

### Purpose

This chapter has two purposes. The first purpose is to develop a procedure for the use of airphotos to predict inorganic sub-surface soils. This is to be done using, in so far as possible the procedure now applied to surface soils. To apply this procedure with confidence to the overall goal of the thesis, that of determining in so far as possible the applications of airphotos to foundation problems, the accuracy of the procedure must be determined. This constitutes the second purpose of the chapter.

### Procedure of Study

The work of this chapter fell readily into a four-step arrangement. First, several trial sites were chosen for which boring data taken for the Indiana East-West Toll Road were available. Second, these sites were studied and a tentative procedure developed. With the procedure developed the third step of this section of the study could be instituted; namely, the prediction of the inorganic sub-surface soils at the final test sites. With these predictions made, the fourth step, the checking of the predictions against boring results and evaluating the procedure, could be carried out.

These sites, both for development and final evaluation of the procedure, are located at intersections along the route of the Indiana East-

West Toll Road in Porter and Laporte Counties, Indiana. Eighteen of these intersections were studied in the final analysis of sub-surface soils and several of these eighteen were used to illustrate the procedure developed. The results of these eighteen examinations are presented later.

## Sub-Surface Soil Prediction Procedure

The procedure used to predict sub-surface soils from airphotos is divided into two general phases: a preliminary investigation of the area in which the site is located, and a detailed investigation of the specific site to be studied.

### Preliminary Investigations

The preliminary investigation consists of the application of the procedures developed at the Airphoto Laboratory of Purdue University for the prediction of surface soils. Included in this is a literature study, and airphoto mosaic study, and a detailed element analysis on an area basis (8). Detailed ground checks are not to be used. This procedure has been amply presented previously and, therefore, will not be discussed herein. This phase of the procedure is used to determine the general characteristics of the parent materials which may then be used as a basis for detailed study of the exact site of interest.

### Detail Investigations

In this phase of the study all of the photo elements listed in Chapter I are employed to delineate detail changes in depth relationships and materials in the profile. While all airphoto elements enter into the analysis certain of these elements can give more information than others. The elements depicted herein were shown in the pilot studies to have this greater application. These elements are topography, tone, erosion, and environment. Environment strickly speaking is not in itself an airphoto element.

In this study only one land form is examined. In this one land form the regional drainage pattern does not change significantly. The culture is constant as is the vegetation. Therefore, these three elements will not be included in the analysis for sub-soils.

<u>Topography</u>. Topography aids in determining profile variations by its uniformity. In glacial materials the greater the roughness of the topography the more likely is the presence of gravel and other coarse grained material. Conversely, smooth topography generally denotes finer grained material (8). An area may be rough but still be uniform in that roughness. For example, sand dune areas are topographically rough but uniform in distribution. Certain phases of the moraine are rough but lack uniformity. The sand dunes exhibit a uniform profile and a uniform topography while the non-uniform moraine exhibits a non-uniform profile. Thus, it is evident that uniformity of topography is an indicator of uniformity in profile. The degree of uniformity within the moraine is an indicator of the degree of uniformity of the profile. To illustrate, Figures 1 and 2 are contrasting in their degree of uniformity. Figure 1 is decidedly non-uniform. Figure 2, while lacking complete uniformity, does exhibit more than Figure 1. Comparison of the profiles in these cases shows that the degree of surface uniformity is a measure of the degree of profile variation.

A second application of topography lies in the change of slope associated with either more resistant or softer material. The location of a slope change in the vicinity of the site is indicative of the presence of a major soil change (See Figure 3). This indicator must

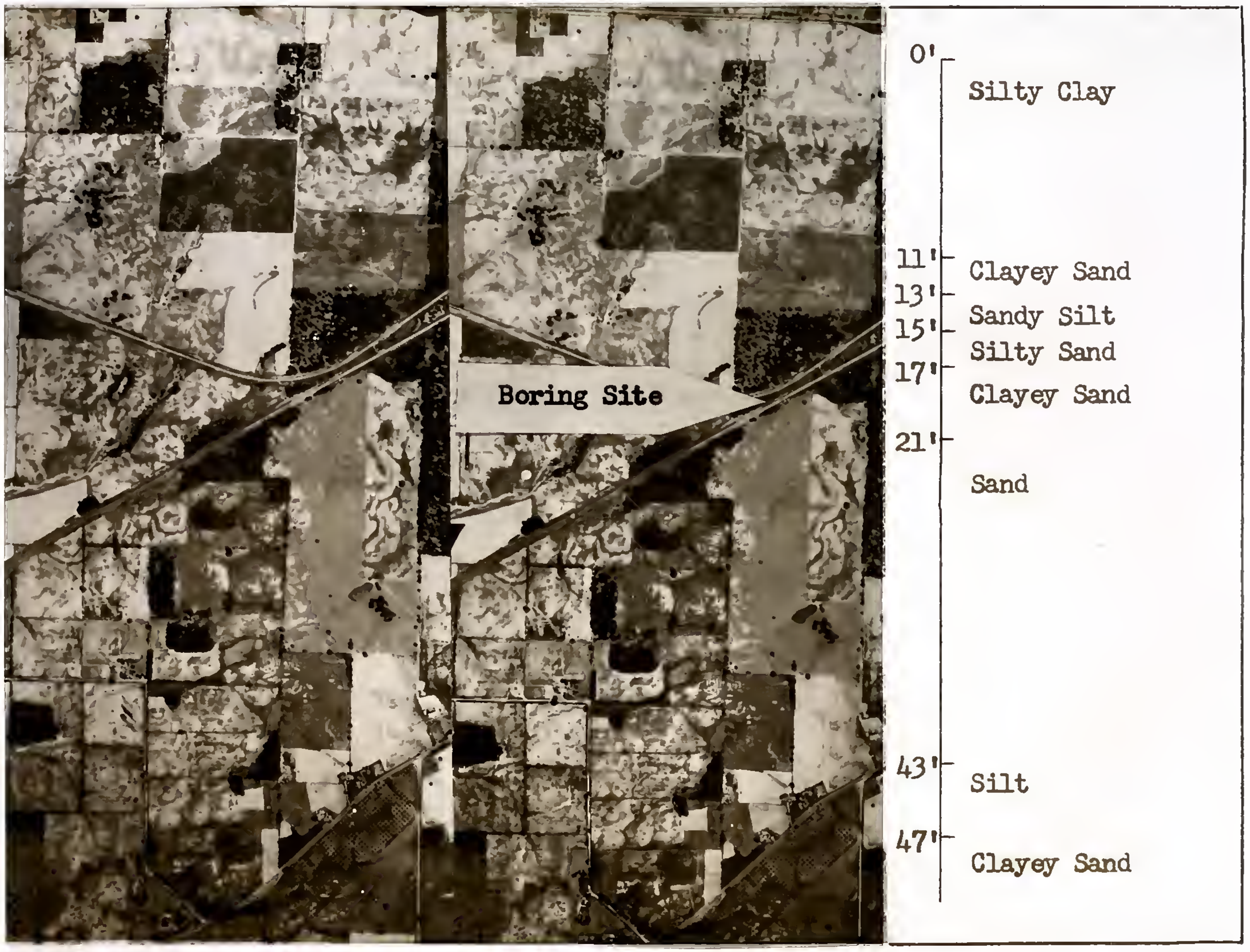



Figure 1. An airphoto stereo pair of a moraine area with non-uniform topography and the attendant soil profile.

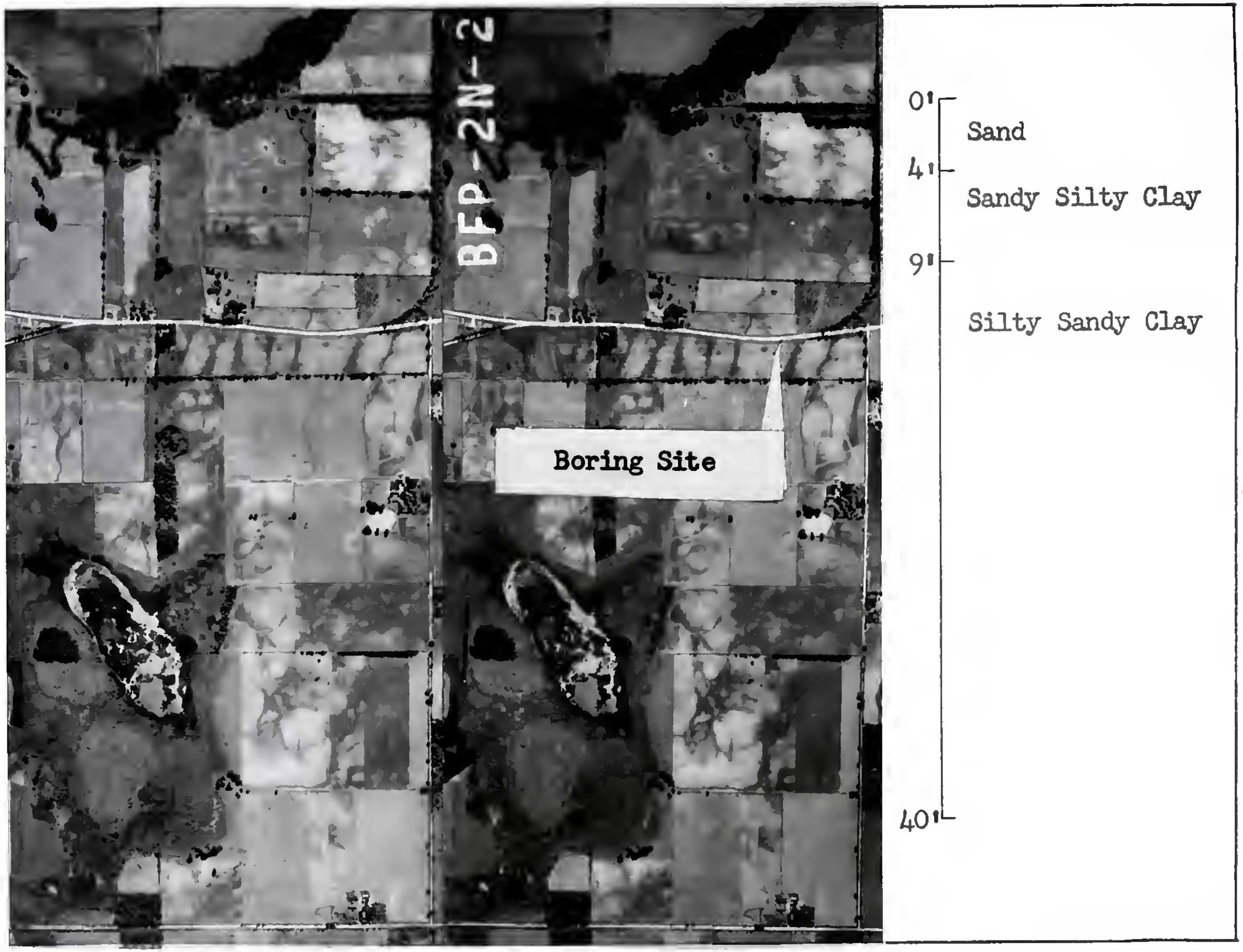



Figure 2. An airphoto stereopair of a moraine area with uniform topography and the attendant soil profile.

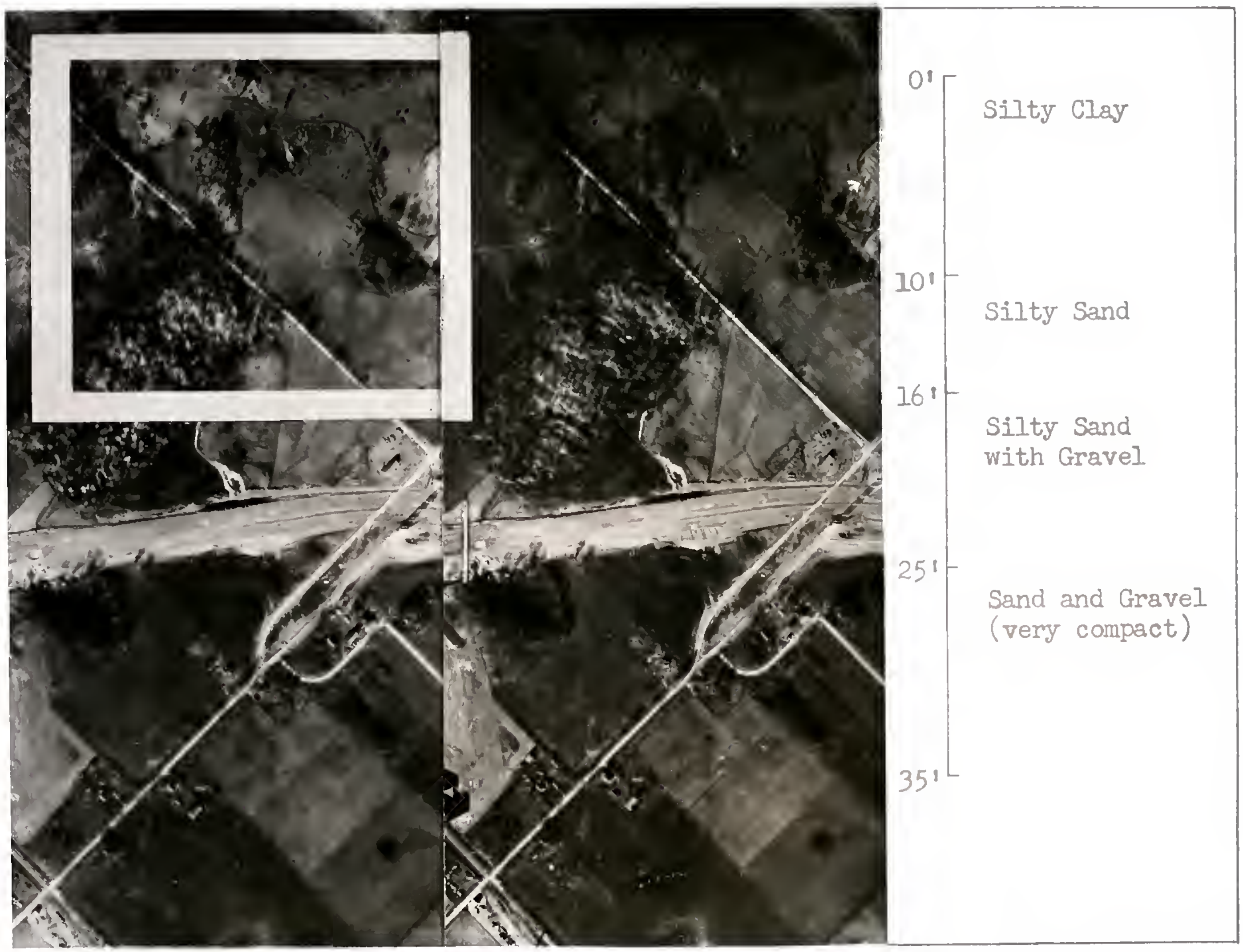



Figure 3. An airphoto stereopair illustrating a topographic slope change and the attendant soil profile.

be carefully used in extending the exposure to the site location. Presence of a topographic change in the area may nullify the application of the slope change. Lack of slope change, while not conclusive, does aid in the conclusion that there is no major soil change in the area.

Slope has another function in estimating depths of overburden in depressed topographic positions. These positions are not open ended channel depressions but are smaller areas within the moraine which are closed within themselves and do not contain muck. Generally these areas are denoted by a tone change from the surrounding area. The filling of these depressions is the result of slope wash. Steeper slopes generally indicate a deeper deposit of sheet wash material in the depression. This is due to the opportunity afforded erosional agents to fill the depression with material from the more easily eroded steeper slopes. Conversely, it should be expected that the sheet wash material be shallow if the slopes are gradual. Besides slope, the size of the low spot must be considered. Larger depressions generally have deeper deposits of fill material because of the added area of possible erosion.

Erosion. Erosion as an indicator of sub-surface soils is limited in its application. Close examination of gullies may show a change of shape within their length. These changes may indicate a change in soil which may be applied to the site under study. Conversely, no significant slope change indicates that changes are minor or are lacking. The difference in elevation through the length of the gully constitutes the major limiting factor. In Figure 3, a hill is present that has gullies with a large elevation change in length. This is shown within the box in the figure. The gully begins with a sharp, steep, V-shape, flattens and widens out during its course down the hill and then again has a sharp V-shape near the bottom. At the bottom the alluvial filling masks the true gully shape. In Figure 1 the gullies have an elevation change similar to that in Figure 3, but there is no dominant shape change. There are, however, several minor changes. These changes are not continuous from gully to gully. This is further indication that the shape changes are due to minor and variable soil changes or other causes. Figure 2 shows gullies with only a small difference in elevation. The shapes are fairly constant but do show a small change to a broader flatter slope when leaving the ridge for the surrounding bottom lands. This would seem to indicate a shallow sandy material on the ridge. Tone aids by its lightness in this supposition. Any depth beyond this shallow surface representation can only be surmized from erosion. These three cases represent the extent to which erosion may be used for direct interpretation of soil changes in depth. They show the need for elevation differences as well as shape changes for interpretation of subsoils. When examination of the slopes is made the change due to alluvial filling at the bottoms of the gullies must not be interpreted as a soil change. When alluvial filling begins in a gully the effectiveness of the gully as a subsoil indicator is finished. The quantity of erosion on slopes bounding closed depressional areas is indicative of the amount and thus the depth of filling in the area. This application has previously been discussed under the relationship of slope to depth of filling.

Tone. Tone is useful as an indicator of change in the overlying material. With a change in relative tone present a change in the surface materials is indicated. This tone change does not indicate the depth of materials. The depth must be found using other elements. Tone is subject to all the variabilities of moisture content, time of photography, date of photography, and reproduction variabilities and thus must be used with discretion (8).

Environment. The environment of the site is that combination of adjacent physical features which may be used to infer some of the characteristics of the sub-surface soils. The location of the site under examination within the moraine proper is used to depict the structure of the sub-surface soils. This is possible from the type of morainic construction dominant when the portion of the moraine where the site is located was built by the glacier. These construction processes were discussed in Chapter I as they pertain to Chamberlin's genetic classification of moraines. In "Kame Moraine" areas, with abundant kettles and generally nearby outwash, stratification should be expected due to the abundance of sluice water indicated by the kettles and outwash. In "Dump Moraine" areas, generally located in the central section of this moraine a variable profile lacking in stratification should be expected. The north edge of this moraine, especially in the western end of the section from Valporaiso to the Michigan border can be classed as "Lodge Moraine." This class of moraine, identifiable by its position and more uniform topography has a more uniform profile without stratification. Certain of the sites studied were located on outwash material at the edge of the moraine. This introduces a two layered system where outwash overlies moraine. The environment of the site where outwash is closely adjacent to the moraine identifies this layered system. A similar situation occurs when lakebed is adjacent to moraine. The depth of the overlying lakebed or outwash materials is primarily a function of the moraine slope as depicted from the element topography.

It should be remembered that the above discussion of environment applies only to the one moraine under study, especially in reference to internal morainic position. With other types of moraines entirely different environment relationships may have to be worked out.

Examples

To further illustrate the applications of the previously discussed elements, Sites 17 and 14 of the eighteen sites used in the final analysis will be used as examples.

Site 17. Site 17 is shown in Figure 3, and is located in northeastern Laporte County at the intersection of the Indiana East-West Toll Road and Noviate Road. The Engineering Soils Map of Laporte County, prepared as a part of the soil mapping program of the Airphoto Laboratory at Purdue University, places the site in moraine. This section of the moraine is described in the literature (13) as having a sandy parent material. The agricultural soils map (25) places the site in Otis Loam which is a depressional silty clayey soil. The surrounding complex by agricultural standards is a Galena Silt Loam which has a silt with sand and clay as the parent material (1). The general parent material is therefore a sandy silt with some clay.

The Drainage Map of Laporte County, prepared by the Airphoto Laboratory at Purdue University shows a kettle hole drainage pattern for the area encompassing this site. This indicates fairly porous sub strata. Thus, the clay portion of the parent material should be replaced by a larger percentage of sand. Topography by its roughness indicates that a coarser material than sand is present. The preliminary analysis using previously compiled airphoto analysis information, agricultural information, literature and the area element analysis indicates a silty sand with gravel as the parent material.

The topography at the site area is exceedingly complex. At the immediate site a topographic low occurs. This is not extensive but does evidence a dark tone. The tone plus the low spot indicate a fine grained soil as substantiated by the Otis Loam agricultural classification. The rises on each side of the site are gradual and fairly shallow indicating that the fine grained soils (silty clay) are shallow. The writer approximates their depth as 7 feet.

Examination of the surrounding topography reveals a distinct slope change from a moderately steep slope to a practically vertical slope. This slope change is located within the box in Figure 3. The check boring site is at the overpass in the right center of the photo. The slope change is located about 25 feet lower than the site on the same hill as is the site. The break continues in a level plane and can be traced for a good distance around the hill. This extensive level continuation of the slope change around the hill indicates that the material change causing the break is extensive. Thus, extending the material change into the hill beneath the boring site appears reasonable.

The break to the vertical slope indicates a very dense material probably a gravely material well compacted. The exposed portion of the steep slope shows a thickness of at least 10 feet and probably more. The non-uniformity of the topography is readily evident. This introduces the probability of considerable variation in the profile.

Examination of Figure 3 shows also a change in gully shape at the same level as the topographic slope change. This shape alteration is from a steep V-shape to a flat broader V-shape as if active erosion is hindered by the more resistant, compact material. When the edge of the compact material is reached the sharp V-shape with very steep gradient can again be found. This indicates that the compacted material is granular.

The environment of the area, adjacent as it is to the outwash area and with numerous adjacent kettles, introduces stratification into the profile.

Compiling the above, the predicted profile is a shallow 7-foot layer of silty clay followed by a silty sand with gravel layer which is stratified. At the 25-foot level a compact layer of gravel with sand starts and extends for at least 10 feet more. The actual profile as taken from the borings at the site in Figure 3 shows a 10-foot silty clay layer underlain by 6 feet of silty sand with the following 9 feet to the 25-foot level as a silty sand with gravel. This section shows stratification and numerous minor variations. At the 25-foot level a very compact sand and gravel mixture is encountered extending to the bottom of the bore hole at 35 feet. Agreement at this site is very good. The major change was correctly located and correctly interpreted. The stratification indicated by the environment and complex profile indicated by the non-uniform topography is also present.

Site 14. Site 14 is shown in Figure 4. The site is located in north central Laporte County. The engineering soils map of Laporte County prepared as part of the soil mapping program of the Airphoto Laboratory at Purdue University places the site in the outwash area immediately adjacent to the Valporaiso moraine. The Agricultural Soils Map of Laporte County (25) indicates that the site occurs in a Tracy Loam. In the process of design for the Indiana East-West Toll Road the engineering properties of the agricultural soil types encountered were analyzed and the general profile characteristics detailed. These generalized profiles and their engineering characteristics are presented in Appendix A. Bulletin 87 of the Purdue University Research Series (1) assigns a silt-clay-sand-gravel mixture as the parent material. This is in agreement with the literature as to expectations from outwash materials. Thus for the preliminary prediction the parent material is a silty-clayey-sand with gravel.

The environment of the site at the tip of an old outwash channel between two morainic knolls indicates that sluice water action was great. Therefore, the finer materials should be lacking from the profile. The environment shows also a two layer system of outwash possibly overlying moraine.

The topography is rolling and more subdued than the moraine of Site 17, but is still lacking in uniformity. This introduces variability in the profile. The gradual slopes of the adjacent knolls if extended under the outwash would indicate a shallow bed to the outwash

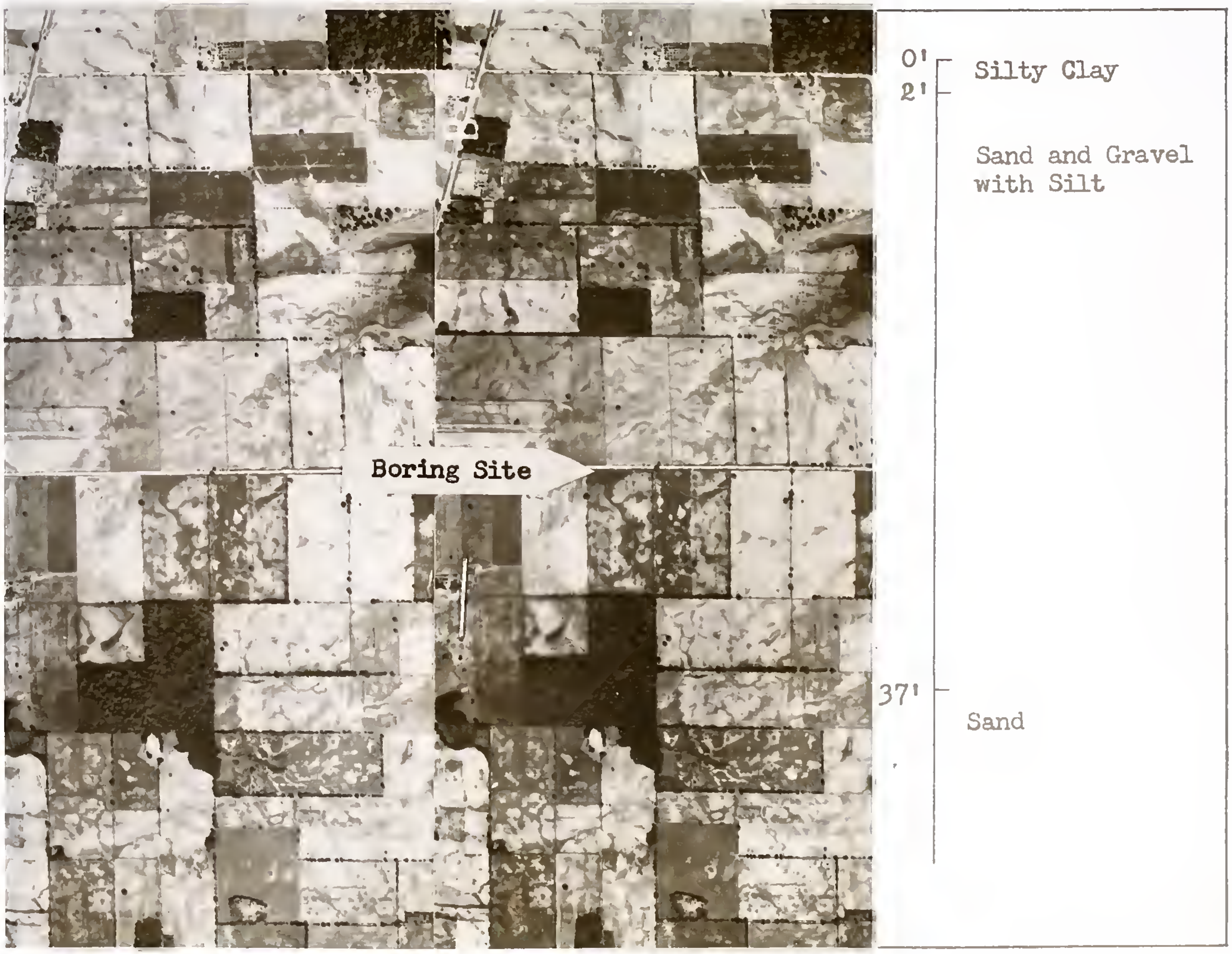



Figure 4. An airphoto stereopair of Site 14.

stream, but the width and environmental indications of extreme water action add considerably to the depth to be expected. The writer estimates this at about 20 feet.

The tone of the site is noticeably darker than the surrounding area. This must be the result of recent wash onto the area. This dark tone suggests a silty clay surface soil estimated at from 2 to 3 feet thick.

Erosion does not add to the analysis in that sufficient depth of exposure of the flat V-shaped gullies is not present.

The prediction dictated by the above analysis is one of 2 to 3 feet of silty clay over 20 feet of silty sands and gravels in turn resting on the silty sands of the moraine. There is considerable stratification and other minor variants present in the profile.

The agreement between the expectations and the actual boring results was good except for the depth of the outwash materials and the lack of silt in what has been interpreted by the writer as the underlying moraine. The boring profile is illustrated in Figure 4.

# Results

## Detail Available

Early in the progress of the work it was realized that the detail available from the study was limited. One item encountered during an early reconnaissance was a deciding factor in the decision to limit the detail to be attempted in the predictions. In Figure 5 is a sketch of a buried channel. That the encountered profile change is a buried channel is evident from the V-shape of the profile, the induration of the material as compared to that surrounding the change, and the reversal of stratification from tilted in the surrounding material to horizontal in the channel itself. In Figure 6, which is an airphoto stereopair of the site, the writer could find no element or combination of elements depicting this known condition. That the area was stratified and contained profile variations was readily evident from the topography and environment. Progressing further into the study it was determined from site studies similar to those shown in the above example that major variations in profile are discernable. It was further determined that the degree of variation of the profile could be approximated from the airphotos. With these factors in mind it was decided to limit the prediction attempts to a delineation of the expected parent material, the degree of variation to be expected in the profile and identification of major changes with the expected depth of these changes. The accuracy of the developed method was to be evaluated from the standpoint of the successful prediction of these three items.

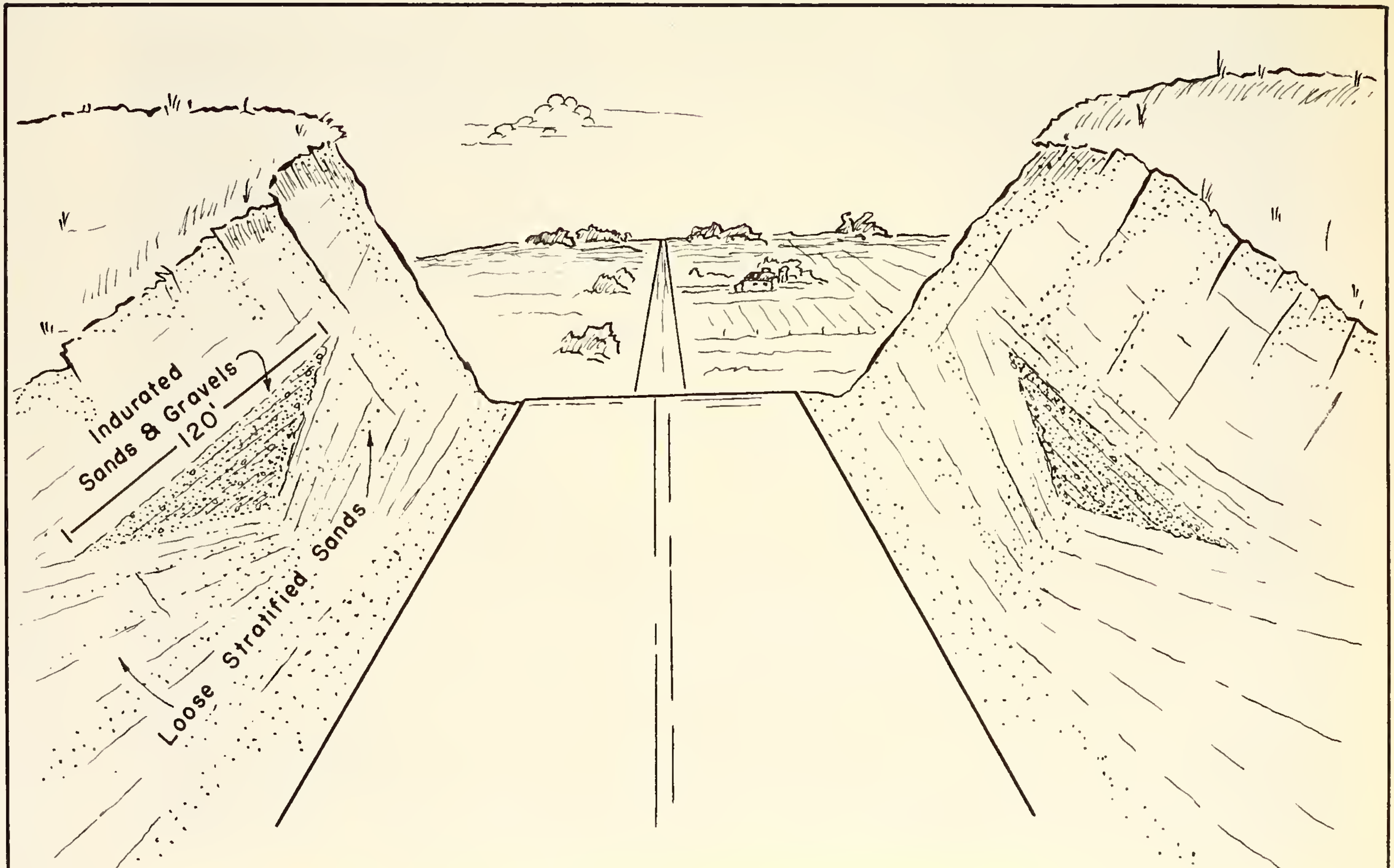



Figure 5 Sketch of a Small Buried Glacial Channel Exposed in a Highway Cut.

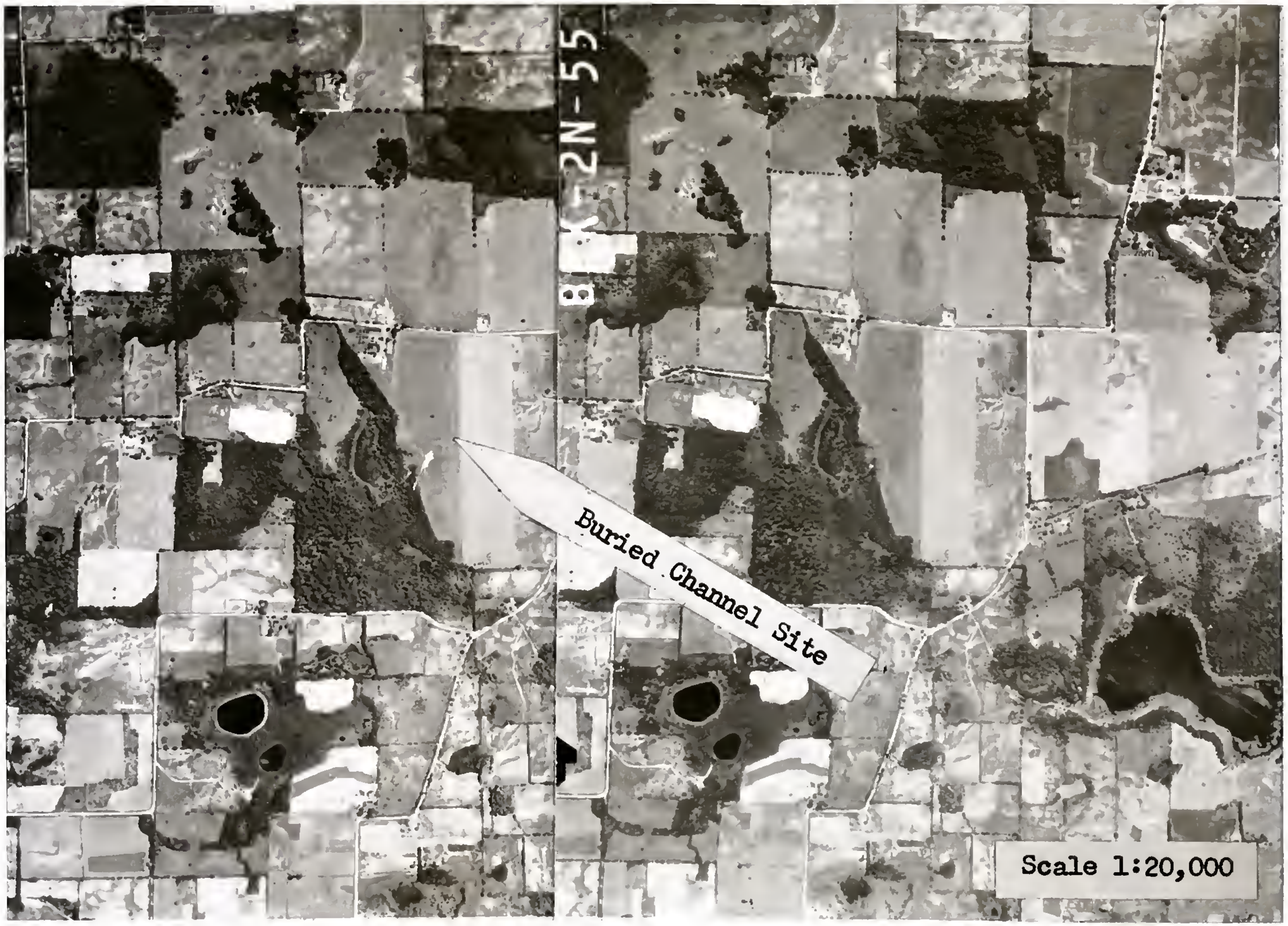



Figure 6. An airphoto stereopair of the area encompassing the buried channel site.

Scale Limitations

The second or detailed phase of the investigation is hindered greatly by airphotos in which the scale is too small. Much detail is missed in studies with photos at the conventional scale of 1:20,000. The gully slopes and shapes, the topographic slope changes, and minute tonal variations are difficult if not impossible to obtain. If the scale is doubled to 1:10,000 the detail is obtained in the quality desired. To illustrate this loss of detail, Figures 6 and 7, both of the same area are presented. Figure 6 is at a scale of 1:20,000 while Figure 7 is at 1:10,000 scale. The contrast is readily seen. The optimum condition for a study such as this requires two scales, the smaller, 1:20,000 for the preliminary investigation and the larger, 1:10,000 for the detailed or final study.

Accuracy Developed

Presented in Appendix B are abbreviated studies, predictions and comparisons of the 18 sites used as final test sites. These sites are all located in Figure 8. In total the predictions showed good agreement with the boring data. At only one site was the correlation poor. At the seven sites where major material changes occurred each was anticipated (Sites 3, 4, 11, 12, 14, 15 and 17). In four of these cases (sites 3, 14, 15 and 18 ), while the change was indicated the depth of occurrence was poorly approximated.

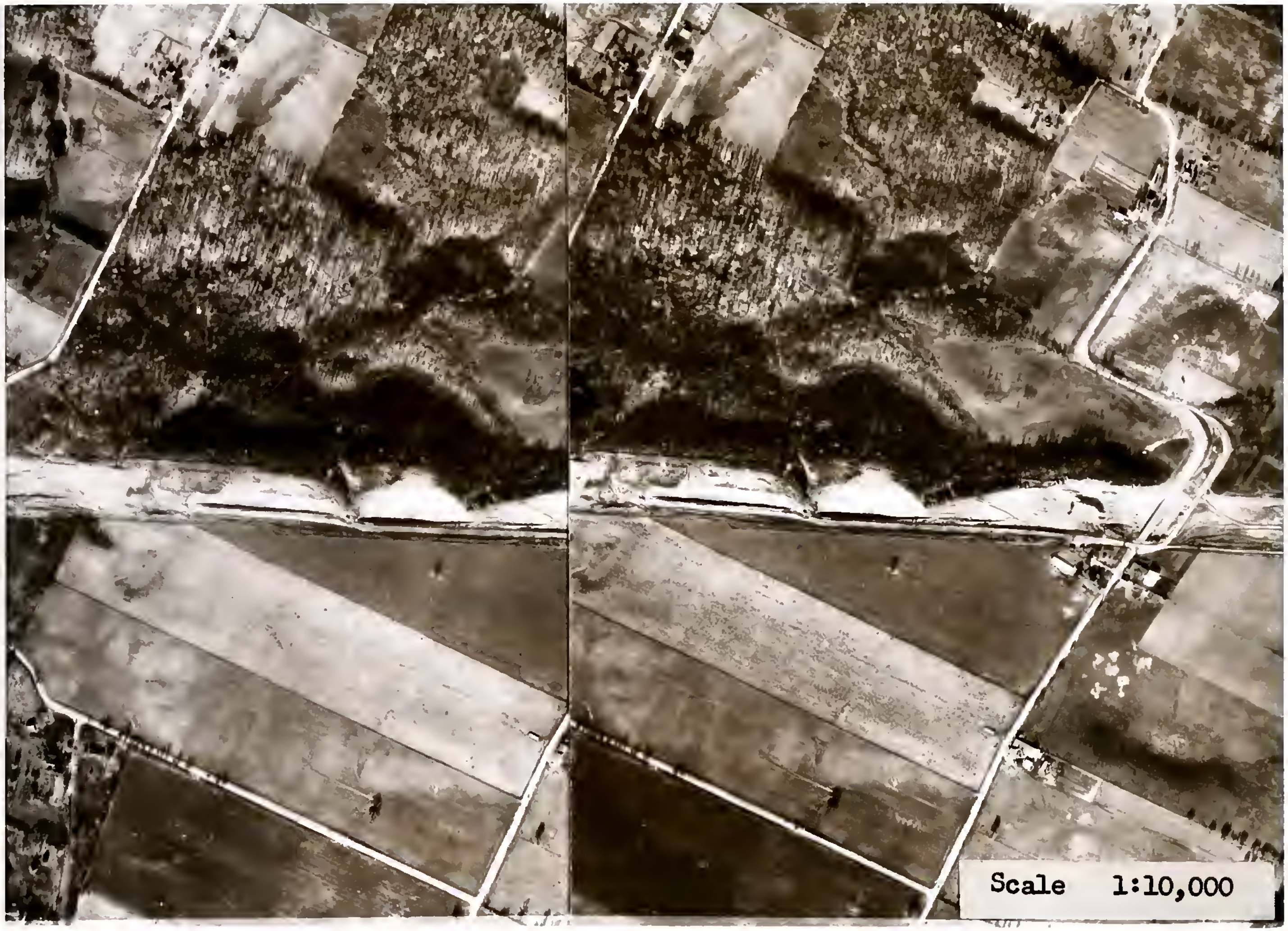
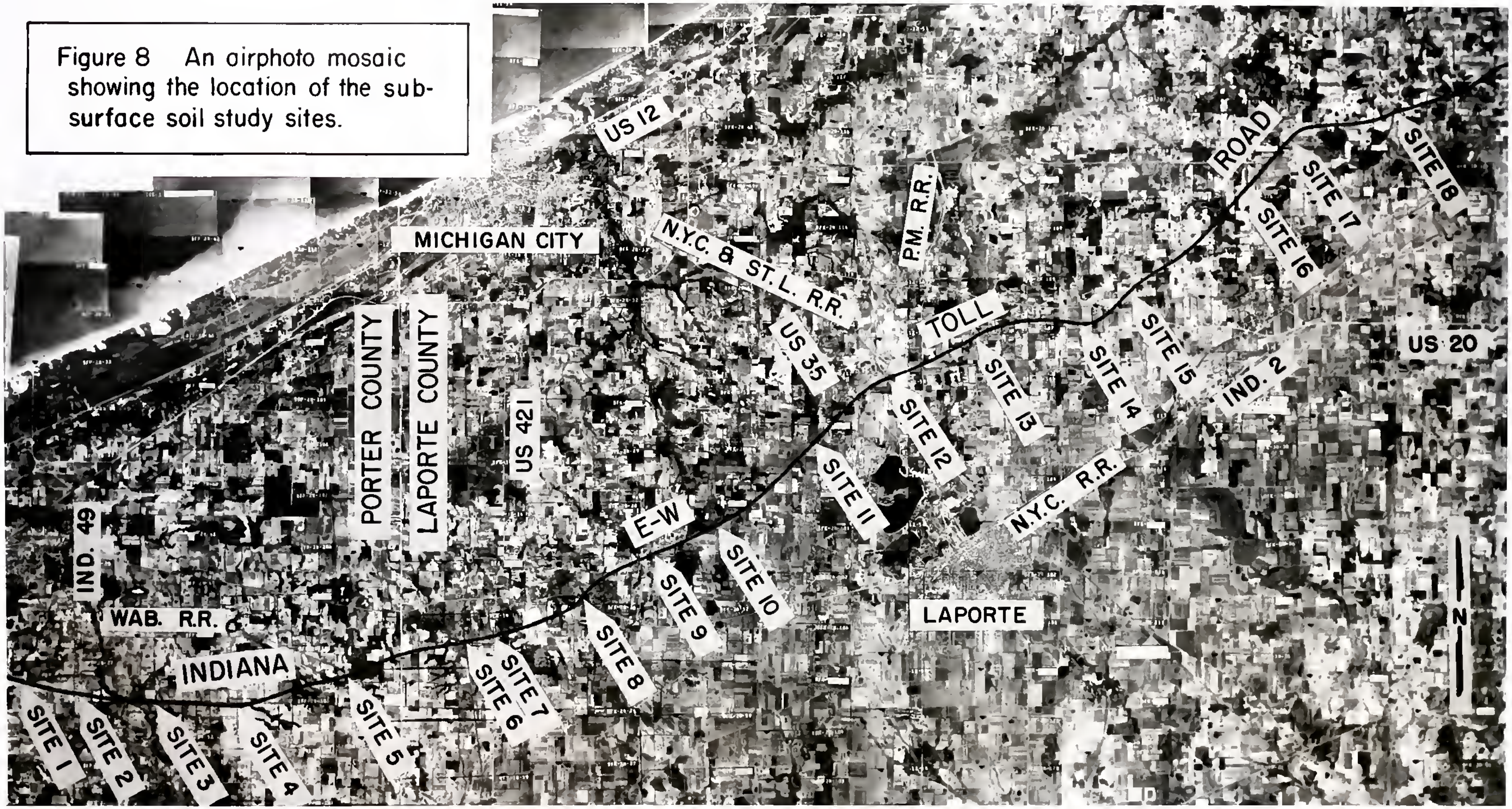



Figure 7. An airphoto stereopair of a portion of the area in Figure 6 at a larger scale.

Figure 8 An airphoto mosaic showing the location of the subsurface soil study sites.



## Conclusions

Using the procedure outlined below, major soil changes, the degree of variability of the profile and the major constituents of the parent material can be determined. Briefly, the procedure consists of two steps: a preliminary stage, where the parent material of the area is determined using previously developed techniques; and a second, or detailed stage, where the elements of topography, tone, erosion and environment are used to determine the degree of variability of the profile and the major soil changes. This procedure was tested only in the Valparaiso Moraine and a narrow fringe of the adjacent outwash between Valparaiso, Indiana and the Michigan-Indiana state boundary. Another limitation is in its application in depth to approximately forty feet, the average depth of the check borings available. Further, the major soil changes predictable by this method are those which have surface representation such as those with alluvial depressional conditions or overlapping boundary conditions.

The accuracy within these limitations is good. The greatest lack of accuracy comes with the prediction of the depth of the major soil changes. However, the general magnitude of the depth was correctly ascertained in all the cases studied.

# CHAPTER III

# MUCK DEPOSIT PROFILES PREDICTED FROM AIRPHOTOS

## Introduction

### Purpose

Muck pockets represent a special case of a major soil change as outlined in Chapter II. Because of the repetition in this locality and the undesireability of the material it was decided to make a special effort at prediction of this type soil. The purpose of this chapter is therefore to develop a procedure for the prediction of muck deposit profiles using airphotos. The procedure is to be evaluated as to the detail available and the accuracy developed.

### Procedure of Study

The procedure used in this section of the study was similar to that used in Chapter II. A number of trial sites were studied and a trial procedure developed. Then eighteen sites were analyzed using this trial procedure. The results were then studied and evaluated.

### Background

There are approximately 80 million acres of peat and muck lands in the United States.(27). Most of this acreage occurs in the northern glaciated states in the form of pockets developed in depressions of varying size left by the glaciers. These peat and muck deposits have been developed from bog and swamp vegetation and sphagnum mosses primarily through the action of bacteria.

There are four principle types of peat: sedimentary, fibrous, woody and sphagnum (27). Their differences are principally due to the types of vegetation which have gone into producing them. Sedimentary peat is built up from algae, underwater plants such as pond weed, blown in vegetation from land dwelling plants and finer sediments washed or blown into the pond. The anchored (roots in soil) plants such as cattails and water lillies produce fibrous peat. Woody peat is the result of the swamp type vegetation of berry bushes and certain tree specie. Sphagnum peat is the result of the growth of sphagnum mosses. This type of peat may develop on high ground or as raised bogs, not necessarily in depressions.

Agricultural soil technicians differentiate peat and muck on the basis of mineral matter contained, but for a general definition muck is decomposed peat (27). Muck is thoroughly decomposed, fine textured and uniform while peat is not thoroughly decomposed, retaining its fibrous structure and lacking in uniformity. When the term muck is used in this writing, either soil, muck or peat, may be present.

The muck deposits studied herein are all located, in compliance with the area limitations, in the Valporaiso Moraine or its immediately adjacent outwash or till plain. All deposits are filled depressions and are of varying sizes. Some muck deposits are formed in a valley or sluiceway position where waters are ponded by the silting up of the lower extremities of the stream. These deposits are not considered herein. Only those formed in kettle-like depressions are studied.

Muck deposits can be identified on airphotos from their dark tone and their appearance as locally flat plains in a depressed topographic position (8). Drainage is generally absent or artificial with some exceptions where narrow streams traverse the deposit. Gully erosion does not occur within the deposit.

## Muck Deposit Profile Prediction Procedures

As with inorganic sub-surface soil profiles a two-step procedure is used. The steps are very similar to the inorganic procedures with a preliminary and a detailed investigation constituting the two steps.

### Preliminary Investigations

As in Chapter II the first step in the procedure is the determination of the area parent material through the use of the previously developed procedure consisting of a literature study, a mosaic study, and an airphoto element study (8).

### Detailed Investigations

In line with the modifications mentioned in the introductory chapter certain liberties were taken with the pattern elements. The elements used consisted of topography and erosion.

Topography, the first of the elements, was subdivided into three sub-sections. Certain of these sub-sections are listed as separate elements. These sub-sections are the size, the shoulders, and the environment of the deposit. Size refers to the areal extent of the deposit. Shoulders consist of the immediately surrounding cup of land which contains the muck. Environment refers not to the geographical or physiographic locale, but to the adjacent kettles and topography.

<u>Size.</u> The size of a muck deposit is immediately apparent to the interpreter. On practically any airphoto of the moraine, muck deposits of all sizes and shapes can be seen. Size appears to have a relation to depth of deposit. The smaller the size of the deposit the shallower it

could be expected to be. The reverse would also appear true, that the larger the areal extent, the greater the depth. Looking into the background of the kettle formation reveals that they are formed by deposition of material around ice masses stranded after recession of the glacier (7). Care must be taken in estimating depths of muck deposits from size because of the nature of their formation. When muck is formed it may not and probably does not fill the depression left by the ice (7).

Shoulders. The surrounding topography has been given the name of shoulders. There are two general types of shoulders, steep and gradual. Ground views of the shoulder types are presented in Figures 9 and 10. These shoulders are the result of the shape of the ice block which formed the kettle. Examination of glacial formation will show the reason for this. Glaciers are generally constructed in two zones, a zone of flow comprised of the inner viscous mass and a zone of fracture consisting of the outer more ridged portion (7). Figure 11 shows diagrammatically these two zones. It has been estimated that the zone of flow does not develop until thickness of from 100 to 200 feet have occurred (6). Thus the zone of fracture can be said to average 150 feet in thickness. Comparing this depth to the greater recorded depths of kettles, again 150 feet, the conclusion may be reached that where kettles were forming the zone of fracture had come in contact with the ground (6). If this is the case, the larger ice masses were left standing as their smaller counterparts were floated away to be stranded elsewhere down stream in the outwash. Thus, there are generally two types of ice masses forming kettles, one the larger mass stranded in place and the other,

Figure 9. Ground View Showing the Steep Shoulders of Site S-9

Figure 10. Ground View of the Gradual Shoulders of Site L-4

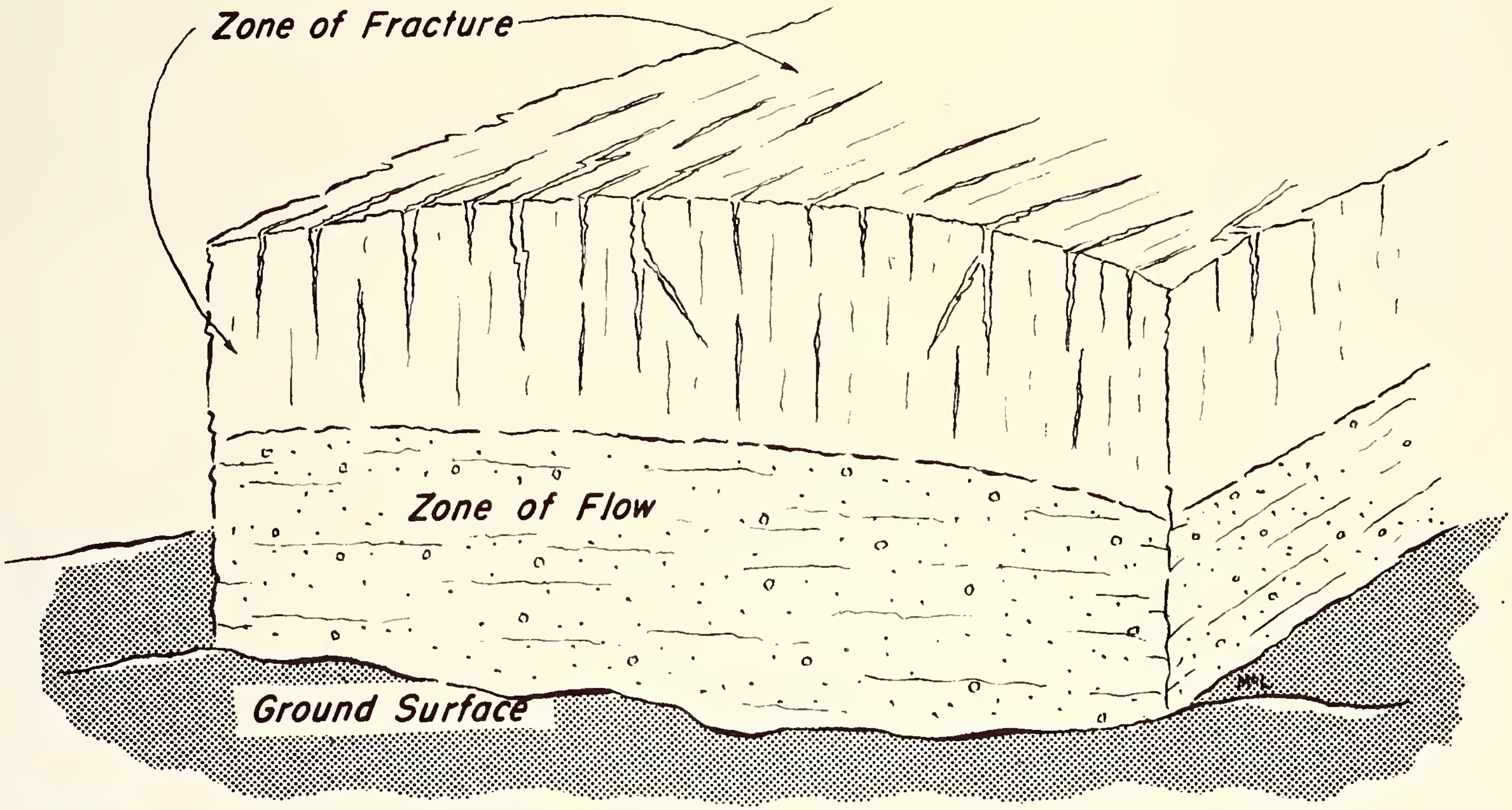



Figure 11 Sketch showing the zones of structure in a glacier.

the smaller mass, generally broken off and floated into position. Examination of the fracture zone shows that the cracks and fissures are the result of tension in the ice and, therefore, can be expected to be fairly regular and generally vertical (6). Conversely, no such regularity can be expected from the smaller rafted ice masses. With the granular materials present in this moraine, little slump into the kettle should be expected. Considering also the geological newness of the area; slump is again minimized. Therefore, vertical or steep shoulders can be used as an indicator that the deposit is probably deep and conversely that the gradual, poorly defined shoulder is indicative of shallow kettles.

Environment. Environment also can be used to distinguish a depth relationship. Kettles formed by rafting ice chunks are generally found in groupings of several small kettles without a large or main kettle in association and they are located on the flank of the moraine. These groupings can be used as an argument for the shallowness of the deposit. When large kettles are encountered there are usually several smaller kettles in the immediate vicinity. These are presumably formed either as a part of the larger kettle or by chunks broken off the larger ice mass. In either case, greater depth than would generally be associated with the sizes should be assumed. The lesser transport distance in case of the separate ice masses and the continuity of the non-transported masses are responsible for this greater depth.

Tone. Tone of the deposit can also be used as an indicator of depth, but must be used with caution. Generally the darker tone is indicative of deeper deposits. Care must be taken to consider the date of photography when using tone. Wet months give a decidedly darker tone to the bog without materially adding to the depth. A light tone may also indicate an alluvial mantle over the deposit.

Size-Depth Relationship. To establish a basis for depth estimation, certain depths were arbitrarily assigned to various sizes of deposits. These depths were assigned with the knowledge that the variabilities associated with the terrain situation and the bounding shoulders would be used to add to this arbitrary criteria. Table 1 shows the assigned values. No values were assigned for the influence of shoulders and environment because of the lack of physically definable properties. The interpreter's evaluation of the influence of these elements was used in place of assigning definite values. Examination of the test sites showed that the kettles with flat or very gradual shoulders closely approximated the depth as in Table 1. As the shoulders became more steep the depth to be added to the estimate from Table 1 increased rapidly. This added depth was proportional to the size of the kettle. Smaller kettles with steep shoulders did not need the same amount of added depth that the larger kettles, with the same steep shoulders did. Those small or medium sized kettles associated with a larger kettle needed considerable added depth. This added depth was not based on the kettle size but on the distance from and the size of the large parent kettle. The larger and closer the parent kettle was to the kettle in question, the greater was the depth added.

Table 1

Estimated Relationships Between Deposit Area and Depth

| Size of Deposit | Unadjusted Depth Used |
|---|---|
| 0 - 5 acres | 0 - 5 feet |
| 5 - 15 | 5 - 10 |
| 15 - 30 | 10 - 15 |
| 30 - 50 | 15 - 20 |
| 50 - 70 | 20 - 25 |
| 70 - 100 | 25 - 30 |
| 100 acres | 30 feet |

Bottom Material. There are three types of material which may form the bottom portions of a muck deposit. These are marl, clay or silt in various combinations and parent material. The muck pocket is generally built in three layers. The top layer consists of muck and peat. The next layer consists of a seal of marl or clay-silt material. Under the sealing layer is generally found the parent material of the area as determined from the preliminary investigation. In some cases the sealing layer may be missing and the muck rest directly on the parent material of the area. Bottom material refers to that soil immediately below the muck. Marl as used here pertains to those calcareous clay-like deposits which are essentially inorganic.

Lack of muck deposition to the bottom of the kettle and the parent material can be attributed to two factors. First the parent material may have been porous enough that water accumulation necessary for aquatic plant life was not present. The remedy for this would be an influx by erosion of fine grained materials such that a water holding impervious bed could be developed. This process would appear as very likely in slack water or outwash muck deposits where the exit and bottom have been silted up thus maintaining a higher water level. This process may also apply to kettle deposits. However, there is the possibility that the impervious seal on the bottom may have been formed by the material within the ice mass as the mass melted and dumped its contents. Further the seal may have been initially absent with a high water table making the deposition of muck or marl immediately possible. The presence of the erosion is therefore indicative of this type bottom, but is not conclusive. The second factor causing the presence of bottom material is peculiar to the deposition of marl. Marl is previously defined as a calcareous and primarily inorganic sediment sometimes called bog lime. It is formed by the deposition of calcium carbonate in the form of aquatic animal shells and droppings from certain lower plants, chiefly Chara (15). Chara has been found in this country in depths from 1 to 90 feet, but is found chiefly in a zone from 24 to 38 feet (26). In this zone below 24 feet, muck forming higher plants do not flourish. It has been determined that Chara has a preference for clay like or loamy soils and will not inhabit sandy soils in the presence of competition (26). Therefore, due to the prevalent vegetation, conditions exist below the 24-foot level for the deposition of marl. As the lake is filled with marl and sediments, higher plants become dominant and the marl is replaced by muck. This vegetation sequence does not preclude the presence of marl at other elevations or as lenses within peat layers at higher elevations. The presence of clay or loamy soils as the parent material adds to the likelihood of marl formation. Sand as the dominant parent material, while a detriment, does not preclude the possible existance of marl.

Example Muck Test Sites

To illustrate the foregoing discussion three test sites with three variations in muck deposits were chosen. These sites were illustrated and analyzed and the attendent predictions made. These examples are presented below. Additional sites were studied and comparisons made. These are presented and discussed later.

Muck Test Site 1. This site is located in Porter County, Indiana on the right of way for the Indiana East-West Toll Road in Contract No. C-16 at Station 1905. It is shown in Figure 12.

The deposit is large in area but is irregularly shaped with several interconnected basins. Specifically the area is 72.1 acres as determined by planimeter. The size would indicate a deposit in excess of 25 feet deep.

The shoulders bounding the deposit are shallow and poorly define the deposit. There are no adjacent kettles. These factors indicate that the values of Table 1 should be used without modification.

The presence of considerable erosion, both sheet and stream, in the area indicates that filling may have taken place in the depression. The gentleness of the slopes plus the apparent shallowness of the deposit make it likely that this has been a gradual filling with not more than 1 to 2 feet of material overlying the fine granular till of the area.

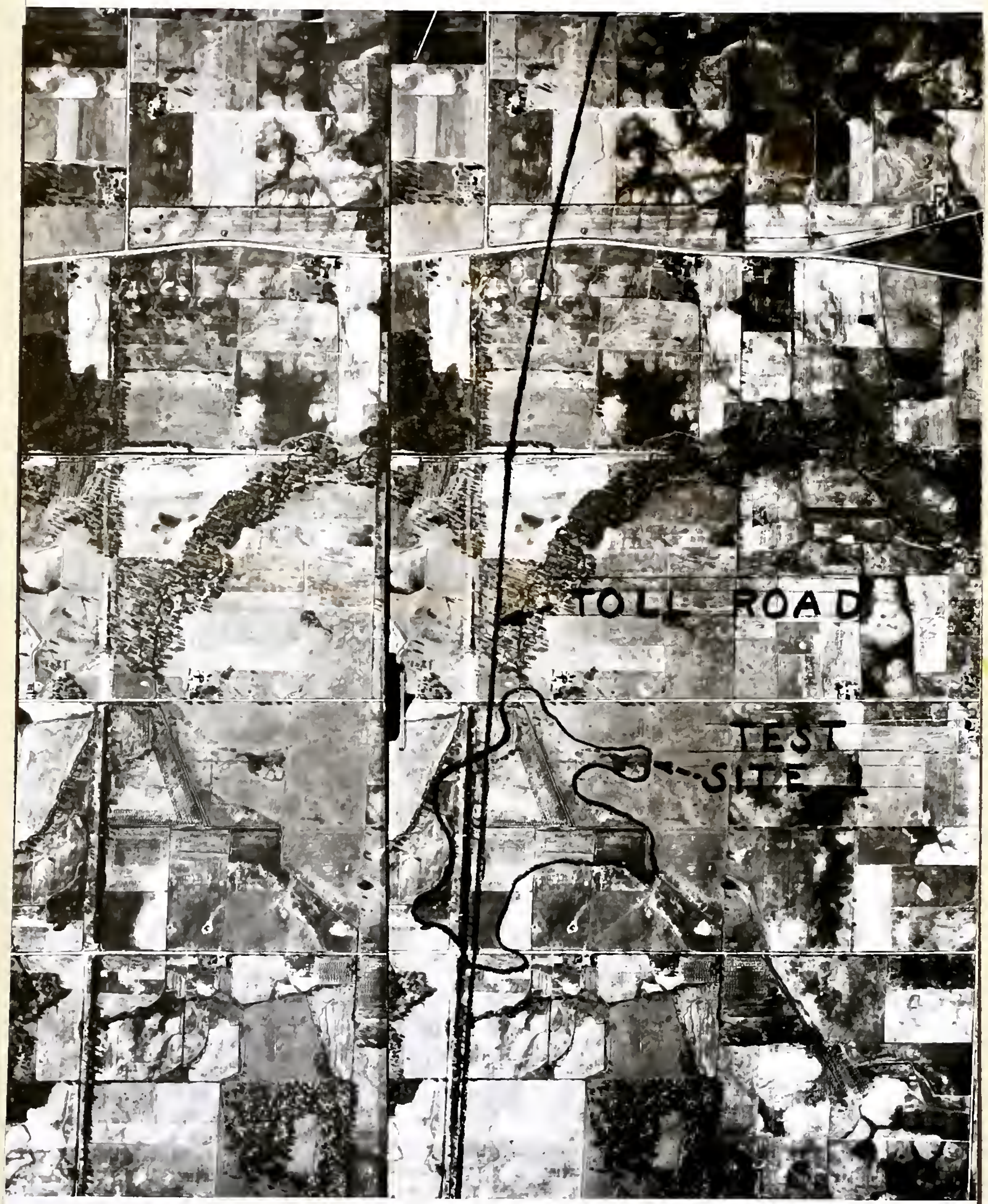



Figure 12. An Airphoto Stereopair Showing Muck Test Site 1.

The tone is light and variable. The photography was taken in the late fall. Combining the fall photography with the presence of man-made drainage in the area accounts for the light tone so that in this case tone is not a contributor either to reduce or increase the depth estimation. However, the variability in tone does indicate variability in the depth.

The deposit should, considering the above factors, have a depth of 25 feet with several feet of clay or marl filling the bottom. Marl is more probable considering the depth.

Muck Test Site 2. Merrillville Bog is located in Lake County, Indiana, Section 14 of Township 35 North and Range 8 West and is shown in Figure 13. This is a large kettle located in the moraine - till plain transition on the north flank of the moraine. The area is 74.6 acres in extent. From size considerations alone, the kettle should exceed 25 feet in depth. The area has gently rolling topography, but not enough slope to avoid some man-made assistance for its developed drainage system. The shoulders are sharp, well-defined and steep indicating a deep kettle. Some allowance should be added to the depth estimation. Because of the sharpness and steepness, the writer estimates this as 10 - 12 feet. The parent material in this area is a heavy clay till. This information was gained through personal knowledge of the area, but could have easily been ascertained by the use of airphotos. The clay soil, the estimated depth of 35 to 37 feet and the presence of erosion combine to emphasize the possibility of marl formation. The depth of muck is estimated at from 22 to 26 feet using the limitations of Chara formation as a guide. The remaining depth contains marl which in turn

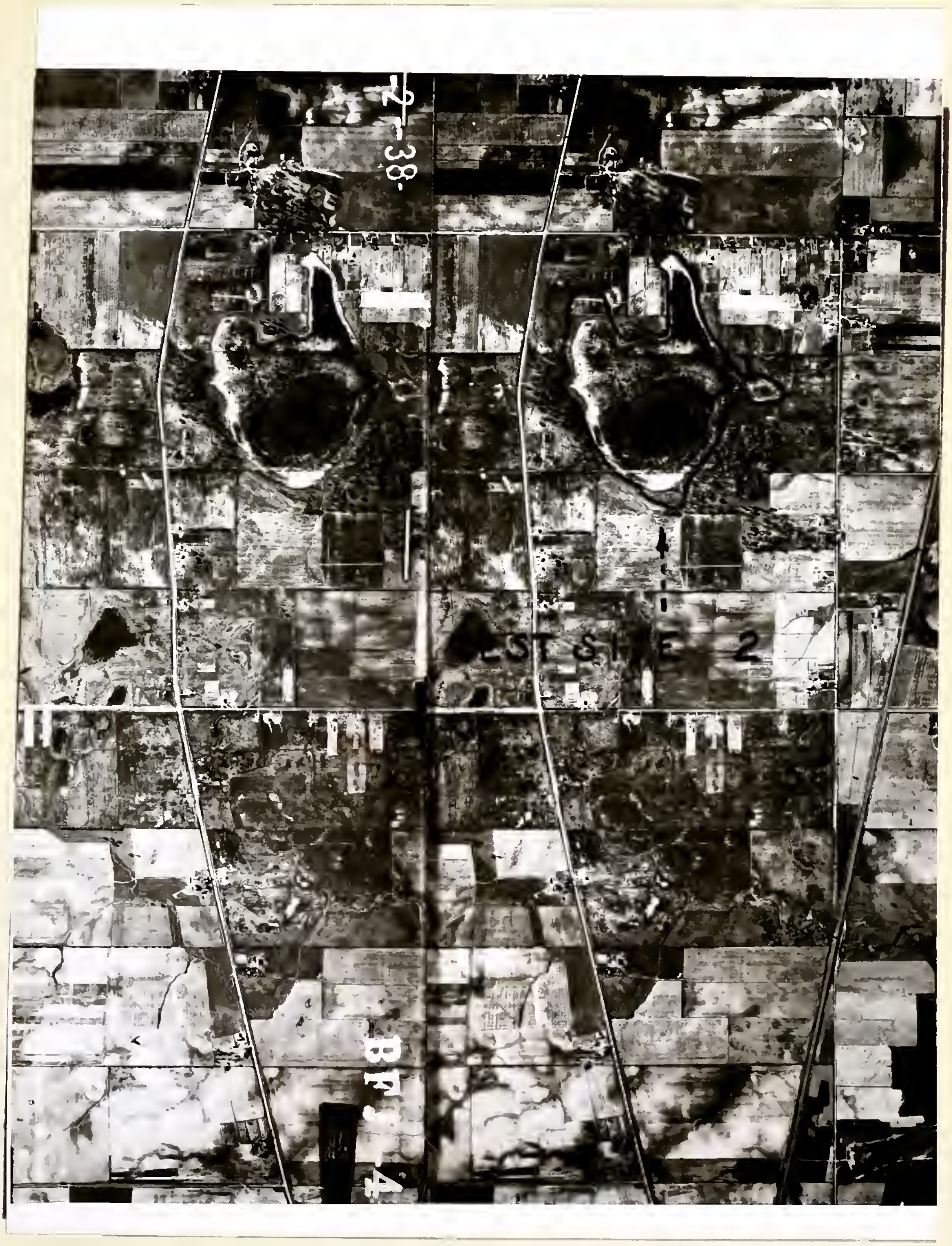



Figure 13. An Airphoto Stereopair Showing Muck Test Site 2.

rests on blue clay at from 35 to 37 feet.

Muck Test Site 3. This deposit is located along the Indiana East-West Toll Road in Section 35 of Township 37 and is shown in Figure 14. It is a small deposit of 8.9 acres. Size dictates a depth of 5 to 7 feet of muck. The shoulders in the surrounding area are steep and the deposit almost fills the available depression. Thus 3 to 5 feet depth should be added making the deposit fall in the 10 to 12-foot bracket. Erosion is present in the adjoining areas, but is of recent origin as denoted by its weakness and its representation primarily in tone. The parent material is primarily granular as denoted by the rough topography and the presence of orchards. It is well drained. The lack of erosion plus the granular parent material and lack of size eliminates important marl deposition. The drainage characteristics make it probable that clay or silt deposition to a depth of 2 feet was needed to institute water holding qualities in the kettle. In summation the deposit consists of 8 to 10 feet of muck with a 2-foot silty- or clayey soil over the silty sand with gravel parent material.


Figure 14. An Airphoto Stereopair Showing Muck Test Site 3.

## Results

The techniques previously hypothesized are here tested. This testing is done by correlating predictions made for various sites with the actual conditions. The actual conditions were obtained from three sources: the Butler University studies on bog pollen and forest succession (10, 18), the borings taken for Design Sections D-2,3, and 4, of the Indiana East-West Toll Road and personal effort. A brief analysis of each site using the major elements previously discussed, together with the predicted profile and the geographical location are presented in Appendix C. The sites are grouped by their size as small (0-15 acres), medium (15-40 acres), and large (more than 40 acres). In Figure 15 the location of those muck sites in Porter and Laporte Counties is presented. Presented in Table 2 are the predicted profile, the actual profile and the degree of correlation. Both, the general and the detailed aspects of the profiles are compared. There were three degrees of correlation used: good, fair, and poor.

### Accuracy Developed

The correlation developed for detailed prediction of muck depths and underlying material can be accomplished only partially due to the lack of check data particularly as refers to depth of underlying materials. In any case the results from muck depths show that detailed prediction of the profiles of muck deposits is not possible using the procedure presented herein. Of the eighteen sites studied, nine showed poor correlation with only three cases giving good results.

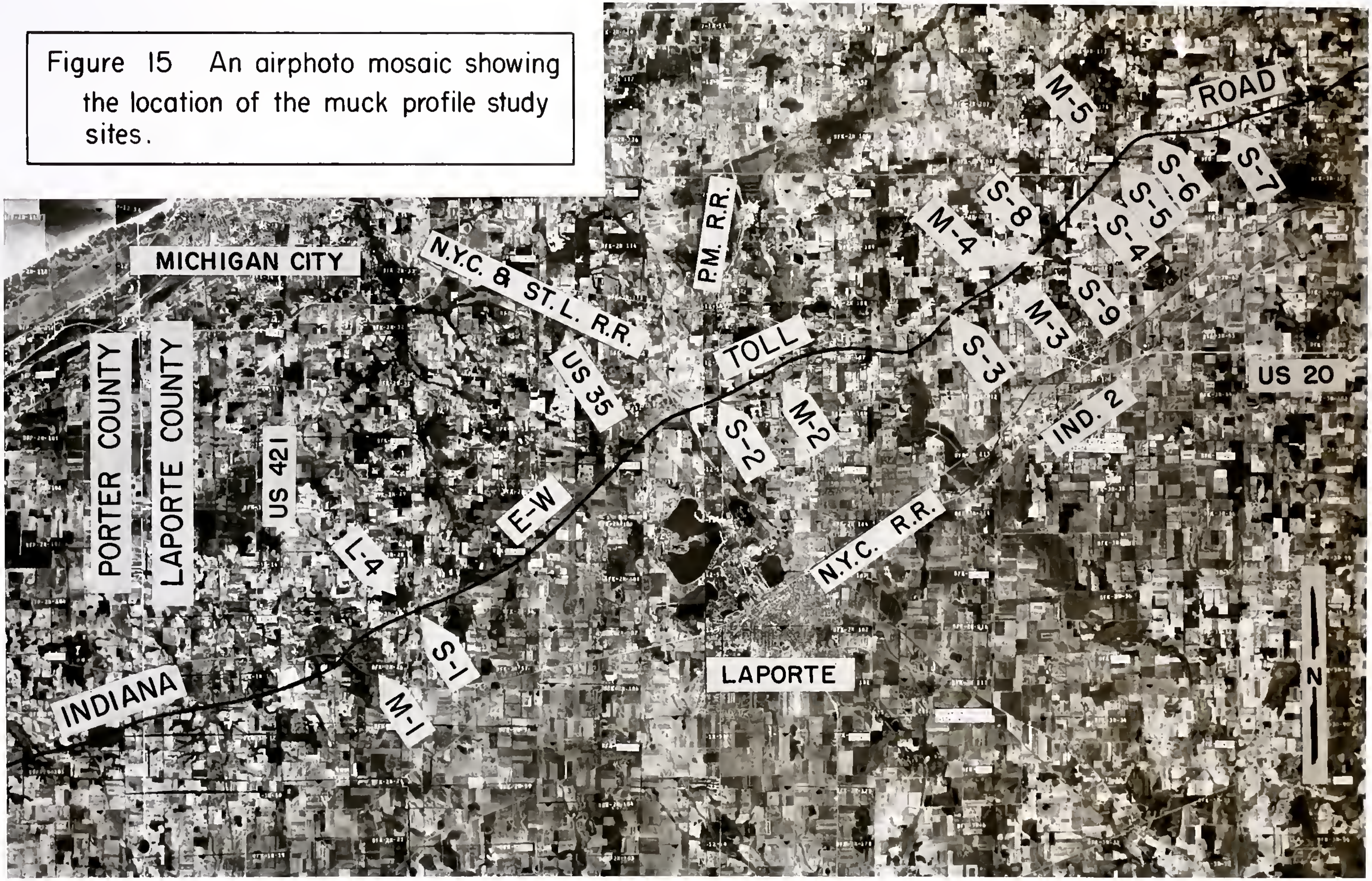



Figure 15 An airphoto mosaic showing the location of the muck profile study sites.

Table 2

Predicted Profiles vs Actual Profiles with General and Specific Correlations

| Site No. | Area | Predicted Profiles | Actual Profiles | Correlation General | Correlation Detailed |
|---|---|---|---|---|---|
| S-1 | 8.9 A | Muck 0-16'<br>Clay 16-18'<br>Till 18-?'* | Muck 0-22'<br>Clay 22-?' | Fair | Poor |
| S-2 | 9.6 A | Muck 0-10'<br>Clay 10-12'<br>Till 12?'<br>Variable cross-section due to fill expected and found | Muck 0-30'<br>Clay 30-45'<br>Till 45-? | Poor | Poor |
| S-3 | 2.5 A | Muck 0-3'<br>Till 3-?' | Muck 0-5'<br>Clay 5-?' | Good | Fair |
| S-4 | 2.2 A | Muck 0-2'<br>Till 2-?' | Muck 0-2'<br>Sand 2-?' | Good | Good |
| S-5 | 6.4 A | Muck 0-7'<br>Till 7-?' | Muck 0-9'<br>Clay 9-?' | Good | Poor |
| S-6 | 4.5 A | Muck 0-9'<br>Till 9-?' | Muck 0-10'<br>Sand 10-?' | Good | Fair |
| S-7 | 3.8 A | Muck 0-5'<br>Clay 5-6'<br>Till 6-?' | Muck 0-2'<br>Clay 2-?' | Fair | Poor |
| S-8 | 6.4 A | Muck 0-13'<br>Clay 13-16'<br>Till 18-?' | Muck 0-34'<br>Clay 34-?' | Poor | Poor |
| S-9 | 1.9 A | Muck 0-5'<br>Clay 5-6'<br>Till 6-?' | Muck 0-8'<br>Clay 8-?' | Good | Fair |
| M-1 | 15.3A | Muck 0-16'<br>Clay 16-18'<br>Till 18-?' | Muck 0-28'<br>Clay 28-40'<br>Sand 40-?' | Poor | Poor |

*Where till is referred to in this table without additional definition, a gravelly, silty sand is implied.

Table 2 (cont.)

| Site No. | Area | Predicted Profiles | Actual Profiles | Correlation General | Correlation Detailed |
|---|---|---|---|---|---|
| M-2 | 15.1 A | Muck 0-15'<br>Clay 15-18'<br>Till 18-?'* | Muck 0-33'<br>Clay 33-?' | Poor | Poor |
| M-3 | 33.2 A | Muck 0-14'<br>Clay 14-16'<br>Till 16-?' | Muck 0-13'<br>Clay 13-?' | Good | Good |
| M-4 | 15.0 A | Muck 0-17'<br>Clay 17-20'<br>Till 20-?' | Muck 0-35'<br>Clay 35-?' | Poor | Poor |
| M-5 | 22.3 A | Muck 0-17'<br>Clay 17-20'<br>Till 20-?' | Muck 0-22'<br>Clay 22-?' | Good | Fair |
| L-1 | 74.6 A | Muck 0-24'<br>Marl 24-36'<br>Clay<br>Till 36-?' | Muck 0-31'<br>Marl 31-41'<br>Clay<br>Till 41-?' | Good | Poor |
| L-2 | 72.1 A | Muck 0-26'<br>Clay 26-28'<br>Till 28-?' | Muck 0-30'<br>Clay 30-40'<br>Sand 40-?' | Good | Fair |
| L-3 | 73.9 A | Muck 0-26'<br>Marl 26-35'<br>Clay-Till<br>35-?' | Muck 0-31'**<br>Clay<br>Till 31-?' | Good | Fair |
| L-4 | 109 A | Muck 0-24'<br>Clay 24-32'<br>Till 32-?' | Muck 0-22'<br>Clay 22-?' | Good | Good |

*Where till is referred to in this table without additional definition, a gravelly, silty sand is implied.

** The depth of muck was assumed from a pollen profile where no differentiation was made in designation of material encountered. Marl does contain pollen and as such may have been included in this undifferentiated profile.

The general correlations show over all good results with thirteen of the eighteen sites showing good or fair correlation. Of the remaining five sites, one was disturbed by blasting for road construction. This disturbance was predicted. A second of these poorly correlated sites was not a true kettle type. There remain only three sites incorrectly evaluated. Two of these were medium sized deposits which were associated with groups of larger kettles.

The presence and type of underlying material was ascertained in each case. The prevailing bottom material is clay. It would appear that in all except an occasional variant in a small kettle the bottom material forms an impervious seal of either clay, in the more shallow deposits, or a clay or marl in the deeper deposits. Thus, good general correlation can be obtained for predictions of occurrance of bottom materials.

There is no check on the value of erosion as an indicator of the thickness of the bottom filling material because of lack of check data.

In the six sites where parent material was encountered in the check data, close agreement was obtained in the general sense in all cases.

## Scale Limitations

The scale limitations discussed in Chapter II apply to this study. The optimum scale being a combination of 1:20,000 for the area study and 1:10,000 for the detail study.

## Summation of Results

In summation, the results show good predictions in the general sense in that the relative depth of the deposits were predicted; the bottom material was determined, and, subject to further check, the parent material was ascertained as it occurred beneath the deposit. The results further show that good predictions in the detailed sense are not obtainable with the procedure used. It was shown that care must be used when evaluating medium sized deposits, these being most susceptible to variation.

## Conclusions

1. The detailed prediction of muck deposit profiles and depths is not feasible using the procedure outlined herein.

2. The general prediction of materials occurring immediately below the muck is possible with considerable accuracy.

3. The indications are that the parent material underlying the deposit are predictable. The data available in this chapter does not warrant a positive statement as to the predictability of parent material.

4. The use of the discussed procedure combined with Table 1 makes possible with fair accuracy the approximation of muck depths in the section of the Valporaiso Moraine studied. The procedure and table are subject to grave errors in any one deposit and thus it is recommended that field checks be made before accepting any predictions especially among the medium sized deposits where the smallest degree of correlation was obtained.

# CHAPTER IV

# CONCLUSIONS

## Conclusions

From the results of Chapters II and III it is apparent that the application of airphotos to foundation problems is limited. The exact limitations as they refer to land forms other than moraine similar to that section of the Valporaiso Moraine studied, remain to be determined. In the area studied, airphotos are a useful tool in a preliminary analysis and prediction of the general soil conditions to be encountered. The analysis of soil conditions must be checked by borings at the proposed site for two reasons. The physical properties, not discernable in the airphoto analysis, must be obtained and the detailed conditions within the general predictions must be determined. The airphoto procedures can be used to eliminate undesirable sites; thus, limiting the boring expense and time. This can be done readily and cheaply. The information gained from the study can further be used to position borings such that they will obtain more appropriate information and can be weighed more accurately when interpreting soil conditions between borings.

## Recommendations for Future Studies

The extension of the work in Chapter II and III to other land forms and other examples of the studied land form is one item for future study. The extension of muck predictions beyond the kettle type of deposit into the stream type deposits is another item to be studied. These constitute the major questions raised by this thesis.

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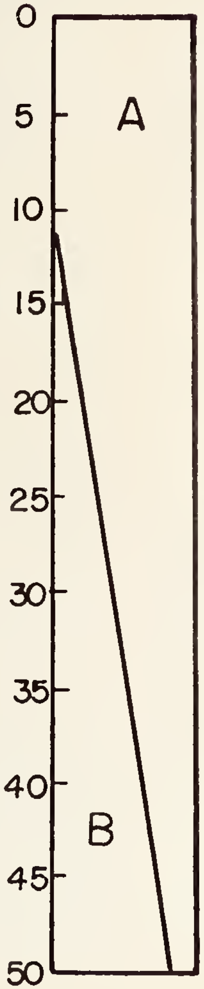
# APPENDIX A

## Appendix A Supplemental Agricultural Soil Profiles

**Washtenaw silt loam**
Nearly level to depressional
Recent wash

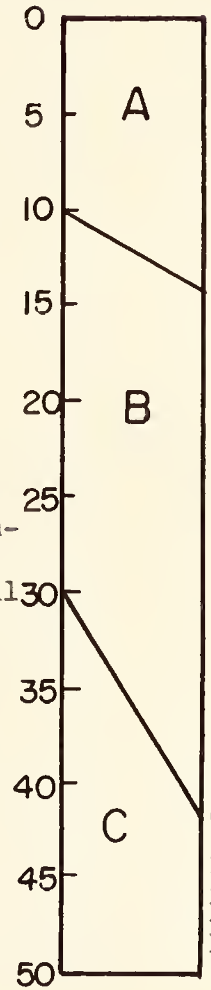



No true profile

Brown Silt Loam
A-4 to A-7-6
L.L. 10 - 80%
P.I. 5 - 20
Pass #200, 60 - 90%

Yellow and Grey Silty Clay Loam grading downward into sandy or moderately plastic till
A-7-5, A-7-6, A-6
L.L. 25-150%
P.I. 10-30
Pass #200, 70 - 95%

**Otis silt loam**
Level to undulating (0-3%)
Medium - heavy calcareous shaley and clayey glacial till

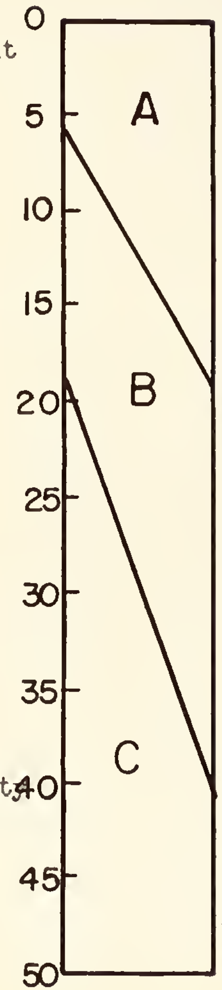



Brown-Grey Loam to Silt Loam
A-4
L.L. 25 - 30%
P.I. 5 - 15
Pass #200, 65 - 85%

Grey-Brown Silty Clay Loam
A-7-6
L.L. 35-55%
P.I. 20 - 35
Pass #200, 70 - 85%

Yellow-Grey Shaley Silty Clay Loam
A-4 to A-7-6
L.L. 30 - 45%
P.I. 15 - 25
Pass #200, 60 - 85%

**Tracy loam**
Level to gently rolling outwash plain
Stratified sand and gravels




Brown Loam to Silt Loam
A-4 to A-2-4
L.L. NP - 30%
P.I. NP - 6
Pass #200, 20-60%

Yellow Brown Clayey Sand
A-2-4 to A-3
L.L. NP - 20%
P.I. NP - 4
Pass #200, 20 - 60%

Yellow-Brown Sand and Gravel with Silt
A-2-4 to A-1-B
L.L. NP
P.I. NP
Pass #200, 5 - 20%

# APPENDIX B

## The Analysis, Prediction and Correlation of Sub-Surface Soil

## Study Sites

### Site 1.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a sandy, silty clay. |
| Topography: | Uniform rolling topography is present, with no slope changes. |
| Erosion: | Broad gullies with flat gradients lacking sufficient exposure to aid specific predictions are present. |
| Tone: | A medium even grey tone of no practical assistance is present. |
| Environment: | The site is in lodge moraine adjacent to a lakebed area. |
| Predictions: | The site has sandy, silty clay for considerable depth without changes. |
| Boring Results: | At depth 0 - 4 feet sandy clay<br>4 - 9 feet silt<br>9 - 40 feet sandy clay |
| Correlation: | The predictions were good. The variation was limited and the major constituent was clay with both sand and silt present in the profile. |

### Site 2.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a sandy silty clay. |
| Topography: | Gently rolling, uniform topography without significant slope changes. |
| Tone: | A medium grey tone of no practical assistance |
| Environment: | In lodge mpraine adjacent to lakebed area. |
| Erosion: | Broad gentle gullies lacking depth of exposure. |

Site 2 (cont.)

| | |
|---|---|
| Prediction: | All elements tend toward uniformity of cross section. There may be sections where the sand content has increased creating a sandy silt material but these are minor variations. A depth of at least 50 feet without significant change can be expected in the sandy silty clay material. |
| Boring Results: | At depth 0 - 4 feet fine sand<br>4 - 9 feet sandy clay with silt<br>9 -40 feet silty clay with sand |
| Correlation: | The predictions were good in that only the proportioning of the materials was at variance with the borings and top sand layer. |

Site 3.

| | |
|---|---|
| Preliminary Predictions: | A sandy silt with clay is the parent material. |
| Topography: | Gently rolling with site located in a depressed position near stream. |
| Tone: | Medium to dark tone. |
| Erosion: | Broad flat gullies except on some hillsides where steep gradients and V-shapes exist. |
| Environment: | On north flank of moraine in lodge moraine area occupying a depressed position. |
| Predictions: | An area of alluvial fill to considerable depth judging from the valley size. Fill material will naturally vary but are overall silty clays with some sand. Depth of fill 10 to 12 feet. Underlying this is the sandy silt with some clay of the parent material. Some variation of the parent material can be expected judging from the abrupt lateral changes in gully shapes. |
| Boring Results: | At depth 0 - 4 feet silty sand<br>4 - 21 feet soft clay<br>21 - 52 feet silty clay with sand and gravel becoming sandy with depth |
| Correlation: | The correlation is fair in that the depth of the fill was under estimated and the major constituent of the parent material was not correct. |

Site 4.

| | |
|---|---|
| Preliminary Predictions: | Parent material is a sandy silt with gravel. |
| Topography: | Rough, non-uniform topography. Site is in a depressed stream bed position. |
| Tone: | Tone is generally light with some mottling but at the site is fairly dark. |
| Erosion: | All gullies exhibit a modified V-whape with gradual slopes. |
| Environment: | North section of moraine with dump moraine characteristics. |
| Predictions: | This crossing occurs in a two layered system of alluvial material silty clays with some sand over a variable parent material of sandy silt with gravel. The alluvial material has a depth estimated at from 15 to 20 feet. |

Boring Results: At depth

| | |
|---|---|
| 0 - 4 feet | silty, trace clay |
| 4 - 6 feet | silty sand |
| 6 - 18 feet | silty clay |
| 18 - 23 feet | clayey sand |
| 23 - 50 feet | silty sand with gravel and clay |

Correlation: The correlation is good except for the surface profile materials. The constituents and depth of the fill and the parent materials were all closely predicted.

Site 5.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a sandy silt with gravel. |
| Topography: | The area exhibits a rough non-uniform topography. |
| Tone: | The general tone is light but at the site a dark tone depression exists. |
| Erosion: | There is an abundance of V-shaped gullies in the area with exposures as deep as thirty feet without significant slope change. |

Site 5. (cont.)

| | |
|---|---|
| Environment: | The site occupies a depressed position in a kame moraine area with many adjacent kettles. |
| Predictions: | The site is filled with an alluvial silty clay mixture to a depth of about 10 feet which lies on the stratified silty sand with gravel parent material which does not change for at least 30 feet and probably more. |

Boring Results: At depth

| | |
|---|---|
| 0 - 3 feet | silty clay |
| 3 - 7 feet | clay |
| 7 - 13 feet | sand with clay, stratified |
| 13 - 29 feet | silty sand with pebbles, stratified |
| 29 - 34 feet | clay |
| 34 - 51 feet | sand with pebbles, stratified |

Correlation: The correlation is fair. The one discrepancy was in missing the clay layer at the 30-foot level.

Site 6.

| | |
|---|---|
| Preliminary Predictions: | An area with silty sand for the parent material. |
| Topography: | Rough, non-uniform topography in surrounding area while site occupies depression between two knobs. |
| Tone: | Tone is medium to dark at the site with surrounding area a mottled light tone. |
| Erosion: | No change is evidenced from the V-shape throughout the depth of the gullies. |
| Environment: | Site is in kame moraine area with attendant stratification. |
| Prediction: | A 10-15 foot layer of silty clay overlies a stratified silty sand to considerable depth. |

Boring Results: At depth

| | |
|---|---|
| 0 - 23 feet | silty, trace sand |
| 23 - 34 feet | sand, trace silt |
| 34 - 48 feet | silt, with sand seams |
| 48 - 52 feet | silty sand |

Correlation: The correlation is poor missing the depth and constituents of the alluvial material and the proportions of the parent material. The stratification was correctly interpreted (see sand seams).

Site 7.

This site occupies an almost identical position to that of No. 6 in the same depressed position.

Prediction: Ten to fifteen feet of silty clays overlying a stratified gravelly silty sand to considerable depth. Photos also show a ten-foot depth of fill material.

Boring Results: At depth

| Depth | Material |
|---|---|
| 0 - 14 feet | fill |
| 14 - 43 feet | silty clays |
| 43 - 51 feet | silty sand with gravel |

Correlation: The correlation is good. The materials are predicted correctly and the depths are in the correct range.

Site 8.

Preliminary Predictions: The parent material is the silty sand of the moraine.

Topography: Site occupies a raised position in rough, non-uniform morainic topography.

Tone: Generally light with some mottling.

Erosion: Steep V-shapes lacking change with depth are the primary gully characteristics.

Environment: The site occupies a position in a kame moraine area with attendent stratification.

Predictions: Site has thin surface layer of silty clay underlain by the silty sand with gravel of the parent material. Stratification makes possible minor changes in constituent proportions.

Boring Results: At depth

| Depth | Material |
|---|---|
| 0 - 3 feet | silty sand with pebbles |
| 3 - 9 feet | silt with pebbles |
| 9 - 23 feet | silty sand with pebbles stratified |
| 23 - 28 feet | silt |
| 28 - 32 feet | silty sand with pebbles stratified |

Correlation: The correlation is good.

Site 9.

| | |
|---|---|
| Preliminary Predictions: | A silty sand with gravel constitutes the parent material. |
| Topography: | Rough non-uniform topography |
| Tone: | A light tone predominates |
| Erosion: | Steep V-shaped gullies without major changes in shape predominate |
| Environment: | Site is located in kame moraine near outwash indicating considerable stratification. |
| Predictions: | The soil is a silty sand with some gravel which is stratified. There is only minor changes with depth. |
| Boring Results: | At depth 0 - 2 feet sandy silt<br>2 - 23 feet sand with silt, stratified<br>23 - 40 feet sand with silt and gravel, stratified |
| Correlation: | The correlation is good with both materials and depths well indicated. |

Site 10.

| | |
|---|---|
| Preliminary Predictions: | A sandy silt surface soil overlies a gravelly silty sand parent material. |
| Topography: | The topography is of the rough, non-uniform type. |
| Tone: | The tone is generally light with some mottling. |
| Erosion: | The gullies have steep gradients and V-shapes without significant change in their 30 feet of exposure in adjacent kettles. |
| Environment: | The site is in the kame moraine near the outwash plain with numerous kettles nearby all indicating stratification. |
| Predictions: | The parent material has numerous minor changes and is stratified in composition. |

Site 10. (cont.)

Boring Results: At depth 0 - 5 feet silt with sand and some clay
5 - 56 feet sand with silt and pebbles, stratified with various densities.

Correlation: The correlation is good with the parent material correctly indicated.

Site 11.

Preliminary Predictions: A sandy outwash material with some gravel is the parent material.

Topography: The topography is gently undulating, uniform and has infiltrations basins and shallow kettles.

Tone: The tone is light with the speckled pattern of the outwash.

Erosion: V-shaped gullies are present in adjacent morainic kettles without significant shape changes but are lacking in the internal drainage outwash area.

Environment: On edge of outwash near kame moraine.

Prediction: At 10 to 20-foot mantle of the sand with gravel outwash material overlies a silty sand with gravel of the moraine. Considerable variation is probable in the underlying material because of the complex situation.

Boring Results: At depth

| | |
|---|---|
| 0 - 7 feet | sandy silt |
| 7 - 27 feet | gravel and sand |
| 27 - 34 feet | clayey, gravelly sand |
| 34 - 40 feet | silty sand with gravel |

Correlation: The correlation is good with the parent materials named correctly and the change at depth indicated in the correct magnitude.

Site 12.

Preliminary Predictions: The parent material is a silty sand with gravel.

Topography: The site occupies a depressed position in rough, non-uniform topography.

Site 12 (cont.)

| | |
|---|---|
| Tone: | Mottled in places with a light tone predominating. It is dark in the pression at the site. |
| Erosion: | Many V-shaped gullies are present but do not show shape changes in their exposed depth. |
| Environment: | Site is located in kame moraine with adjacent kettles. |
| Predictions: | The surface 10 feet are of clayey silt material which is underlain by the stratified silty sands with minor changes indicated. |
| Boring Results: | At depth 0 - 11 feet silty clay<br>11 - 13 feet clayey sand<br>13 - 15 feet sandy silt<br>15 - 17 feet clayey sand<br>17 - 21 feet silty sand<br>21 - 43 feet sand<br>43 - 47 feet silt<br>47 - 52 feet clayey sand<br>52 - 72 feet sand |
| Correlation: | The correlation is fair with the depth of the overlying material closely approximated and the parent material to depth of 40 feet correctly indicated. The presence of the silt underlier was missed completely. |

Site 13.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a silty sand with some gravel. |
| Topography: | The topography is rough and non-uniform. |
| Tone: | The tone is light and mottled. |
| Erosion: | Numerous V-shaped gullies are present but lack slope changes. |
| Environment: | The site occupies an elevated position in the kame moraine with adjacent kettles. |
| Predictions: | The soil is a silty sand with gravel and has only minor variations due to stratification. |

Site 13 (cont.)

Boring Results: At depth 0 - 5 feet silty sand
5 - 8 feet silty clay
8 - 52 feet silty sand with trace gravel and some thin clayey sand lenses.

Correlation: There is a good degree of correlation at this site. The parent material was predicted correctly and the presence of stratification was indicated.

Site 14.

Preliminary Predictions: The parent material is a silty clayey sand.

Topography: The site occupies a depressed position between two knolls. The topography is rolling but non-uniform.

Tone: The tone is light in the surrounding area but dark at the site. A speckled pattern is in evidence.

Erosion: Gully shapes are a modified or flat V. No depth of erosion is visible.

Environment: The site is at the edge of the moraine in the tip end of an outwash stream.

Prediction: Granular material from the outwash will dominate the profile to an estimated depth of from 10 to 20 feet under a silty clay soil accounting for the dark tone. The silty sands of the moraine will then replace the more granular outwash materials. Stratification is present giving many minor variations.

Boring Results: At depth 0 - 2 feet silty clay loam
2 - 35 feet sand and gravel with silt, various densities, stratified
35 - 45 feet fine sand

Correlation: The correlation was fair in that the depth of the outwash was only approximated and the material was not as predicted.

Site 15.

| | |
|---|---|
| Preliminary Predictions: | The area parent material is the silty sand of this section of the moraine. |
| Topography: | The topography is gently rolling but lacks uniformity. The site occupies a semi-depressed position near a kettle hole where the slopes are shallow. |
| Tone: | The tone in the surrounding area is light while at the site a darker tone is in evidence. |
| Erosion: | The shallow V-shaped gullies add little to the analysis due to lack of depth. |
| Environment: | The site is in a kame moraine area on the edge of a muck deposit. |
| Predictions: | The depressed position, dark tone and adjacent muck deposit indicate a shallow (5 feet) deposit of sandy silty clay material. Under this is the stratified and variable silty sand of the parent material. |
| Boring Results: | At depth 0 - 6 feet clayey silt<br>6 - 11 feet sandy silty clay<br>11 - 16 feet sandy silt<br>16 - 46 feet silty sand, stratified |
| Correlation: | The correlation is fair with the descrepancy in the depth prediction of the overlying material. |

Site 16.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a silty sand. |
| Topography: | The site is in a depressed position in an area of rough, non-uniform topography. |
| Tone: | The tone is dark in the depression but light and mottled in the adjoining area. |
| Erosion: | The sheet erosion present is generally V-shaped but lacks the depth necessary for aiding deep soil predictions. |

Site 16 (cont.)

| | |
|---|---|
| Environment: | The site is in a depressed position in a kame moraine where kettles are abundant. |
| Predictions: | At 10-foot silty clay layer overlies the silty sand parent material which is stratified with the attendent minor changes. |
| Boring Results: | At depth 0 - 7 feet sandy clayey silt<br>7 - 18 feet silty sand<br>18 - 32 feet sand, various densities, stratified<br>32 - 45 feet silty sand with gravel |
| Correlation: | The correlation is good with the parent material and the overlying strata both portrayed. |

Site 17.

| | |
|---|---|
| Preliminary Predictions: | The parent material is a silty sand with gravel. |
| Topography: | The site is on a knoll in a rough, non-uniform area. There is a decided slope change on the side of an adjacent kettle. There is a slight depression on the rise occupied by the site. |
| Tone: | The tone is light, except at the site where it becomes darker. |
| Erosion: | The gullies are V-shaped. The slope change noted above is again indicated by both slope and shape changes in the gullies. |
| Environment: | The site is in kame moraine adjacent to outwash with kettles nearby. |
| Prediction: | The surface is a silty clay changing with depth to a silty sand. At about the 25-foot level the material becomes a dense gravel matrix. |
| Boring Results: | At depth 0 - 10 feet silty clay<br>10 - 16 feet silty sand<br>16 - 25 feet silty sand with gravel<br>25 - 35 feet sand and gravel (very compact) |
| Correlation: | The correlation is good with all variants outlined. |

Site 18

| | |
|---|---|
| Preliminary Predictions: | The parent material is a silty sand. |
| Topography: | The area has a roughly rolling, non-uniform topography. |
| Tone: | The tone is generally light. |
| Erosion: | Shallow modified V-shaped gullies are in evidence. |
| Environment: | This is a kame moraine area with numerous kettles. |
| Predictions: | A sandy silty clay surface soil is underlain by a silty sand with stratifications and minor changes. |
| Boring Results: | At depth 0 - 6 feet silty clay<br>6 - 12 feet silty sand<br>12 - 27 feet sand and gravel (stratified)<br>27 - 45 feet sand and gravel (compace) |
| Correlation: | The correlation is fair with the descrepancy in the parent material sizes. |

# APPENDIX C

Analysis of Small Sized Muck Deposits

| Site No. | | Analysis and Location |
|---|---|---|
| S-1 | | See Muck Test Site 3 for analysis and location. |
| S-2 | Location: | Sec. 14 and 15, T37N, R3W, Laporte Co., Indiana on 1954 AAA photos BFK 2N (132-133) |
| | Size: | 9.6 acres |
| | Environment: | Rough moraine area |
| | Shoulders: | Sloping gradually inward with one section fairly steep. |
| | Erosion: | Limited gully erosion present |
| | Predictions: | Original prediction 10 feet of muck. Slope adds 2 feet which are taken up by clay bottom overlying the granular till parent material. Variable cross-section to be expected because of road fill. |
| S-3 | Location: | Sec. 5, T37N, R2W, Laporte Co., Indiana on 1954 AAA photos BFK 2N (209-210) |
| | Size: | 2.5 acres |
| | Environment: | Rolling moraine-outwash transition |
| | Shoulders: | Very gradual shoulders almost completely filled. |
| | Erosion: | None present |
| | Predictions: | Original prediction 3 feet of muck. Shoulder slope and filling counter balance each other. Therefore no alteration of prediction; 3 feet of muck on granular till. |

| Site No. | | Analysis and Location |
|---|---|---|
| S-4 | Location: | Sec. 26, T38N, R1W in Laporte Co., Indiana on 1954 AAA photos BFK 3N (174-175) |
| | Size: | 2.2 acres |
| | Environment: | Rolling moraine - outwash transition. |
| | Shoulders: | No visible shoulders. Completely filled. |
| | Erosion: | None visible. |
| | Prediction: | 2 feet of muck on granular till with no alteration due to shoulders or erosion. |
| S-5 | Location: | Sec. 26, T38N, R1W in Laporte Co., Indiana on 1954 AAA photos BFK 3N (58-59) |
| | Size: | 6.4 acres |
| | Environment: | On moraine-outwash transition. |
| | Shoulders: | Completely filled with flat shoulders |
| | Erosion: | None visible |
| | Prediction: | Original prediction 7 feet of depth. Shoulders have no effect. Final estimate 7 feet of muck on granular till. |
| S-6 | Location: | Sec. 24, T38N, R2W Laport County, Indiana on 1954 AAA photos BFK 3N (58-59) |
| | Size: | 4.5 acres |
| | Environment: | On moraine-outwash transition adjacent to large kettle |
| | Shoulders: | Completely filled with apparently steep slopes. |
| | Erosion: | None visible |

| Site No. | | Analysis and Location |
|---|---|---|
| S-6 (cont.) | Predictions: | Original prediction 4-5 feet of muck. Shoulders add 2 feet to depth. Final estimate 7 feet of muck on granular till. |
| S-7 | Location: | Sec 19, T38N, R1W in Laport County, Indiana on 1954 AAA photos BFK 3N (108-109) |
| | Size: | 3.82 acres |
| | Environment: | South flank of rolling moraine with adjacent kettles. |
| | Shoulders: | Moderately well filled with gradual slopes. |
| | Erosion: | Not prominent but some visible. |
| | Predictions: | Original estimate is 4 feet of muck. Adjacent kettles add 2 feet of depth which is filled with clay by erosion. |
| S-8 | Location: | Sec 34, T38N, R2W in Laporte County, Indiana on 1954 AAA photos BFK 3N (175-174) |
| | Size: | 6.4 acres |
| | Environment: | In moraine - outwash transition adjacent to several kettles both larger and smaller. |
| | Shoulders: | Steep and incompletely filled. |
| | Erosion: | Considerable gully erosion in the area. |
| | Predictions: | Size indicates an 8-foot depth with shoulders and adjacent kettles adding 8 feet. Erosion indicates 3 feet of filling. Final prediction: 3 feet of muck over 3 feet of clay on granular till. |

| Site No. | | Analysis and Location |
|---|---|---|
| S-9 | Location: | Sec 34, T38N, R2W in Laporte County, Indiana on 1954 AAA photos BFK 3N (175-176) |
| | Size: | 1.9 acres |
| | Environment: | Rough morainic topography bordering outwash area. |
| | Shoulders: | Steep, well filled shoulders. |
| | Erosion: | Some slight gully erosion. |
| | Predictions: | Size indicates 2 feet of muck but shoulders add 3 feet. Final adjusted prediction, 4 feet of muck and 1 foot of clay on granular till. |

## Analysis of Medium Sized Muck Deposits

| Site No. | | Analysis and Location |
|---|---|---|
| M-1 | Location: | Sec 2, T36N, R4W in Laporte County, Indiana on 1954 AAA photos BFK 2N (27-28) |
| | Size: | 15.3 acres |
| | Environment: | Rough morainic area with adjacent kettles. |
| | Shoulders: | Steep, moderately filled shoulders. |
| | Erosion: | Considerable erosion, both gully and sheet present. |
| | Predictions: | Size indicates a 10-foot depth with shoulders and adjacent kettles adding 8 feet of which the bottom 2 feet are clay. |
| M-2 | Location: | Sec 12, T37N, R3W in Laporte County Indiana on 1954 AAA photos BFK 2N (187-188). |
| | Size: | 15.1 acres |
| | Environment: | In rough kame moraine with several adjacent kettles. |
| | Shoulders: | Moderately steep and well filled. |
| | Erosion: | Some sheet erosion present. |
| | Predictions: | Size indicates a 10-foot depth. The shoulders and adjacent kettles combine to increase this by 8 feet. There is a 3-foot clay bottom over granular till. |

| Site No. | | Analysis and Location |
|---|---|---|
| M-3 | Location: | Sec 3, T37N, R2W in Laporte County, Indiana on 1954 AAA photos BFK 3 N (175-176) |
| | Size: | 33.2 acres |
| | Environment: | Rolling moraine - outwash transition. |
| | Shoulders: | A completely filled deposit with vegetation masking the apparently gradual shoulders. |
| | Erosion: | Small amount of stream erosion present. |
| | Predictions: | Size indicates 16-foot depth with detracting shoulders balanced by filling. Erosion indicates some filling. Therefore 14 feet muck with 2 feet of clay bottom on granular till. |
| M-4 | Location: | Sec 34, T38N, R2W in Laporte County, Indiana on 1954 AAA photos BFK 3N (175-176) |
| | Size: | 15.0 acres |
| | Environment: | A rough morainic area with adjacent kettle. |
| | Shoulders: | Steep and fairly well filled. |
| | Erosion: | Some stream erosion present. |
| | Predictions: | Size indicates a depth of 10 feet. Shoulders filling and adjacent kettles add 10 feet while erosion detracts 3 feet giving 17 feet of muck on 3 feet of clay over granular till. |

| Site No. | | Analysis and Location |
|---|---|---|
| M-5 | Location: | Sec 23, T38N, R2W in Laporte County, Indiana on 1954 AAA photos BFK 3N (173-174) |
| | Size: | 22.3 acres |
| | Environment: | Rough morainic area with adjacent kettles. |
| | Shoulders: | Moderately steep and well filled. |
| | Erosion: | Some sheet erosion present. |
| | Predictions: | Size indicates 12 foot depth with 3 feet added for shoulders and 5 feet for adjacent kettles. Erosion indicates 3 feet of clay under the 17 feet of muck and on granular till. |

## Analysis of Large Sized Muck Deposits

| Site No. | | Analysis and Location |
|---|---|---|
| L-1 | Location: | Sec 14, T35N, R8W in Lake County, Indiana on 1938 AAA photos BFJ 3 (86-87) |
| | Analysis: | See Muck Test Site 2. |
| L-2 | Location: | Sec 19, T36N, R6W in Porter County, Indiana on 1938 AAA photos BFP 3 (42-43) |
| | Analysis: | See Test Site 1. |
| L-3 | Location: | Sec 35, T34N, R8W in Lake County, Indiana on 1938 AAA photos BFJ 4 (34-35) |
| | Size: | 74 acres |
| | Environment: | Undulating outwash plain just south of moraine. |
| | Shoulders: | Fairly well filled and steep in comparison with surrounding topography. |
| | Erosion: | Considerable erosion present. |
| | Predictions: | Size indicates a 27-foot depth with shoulders adding 8 feet making a 35-foot depth. Under 26 feet of muck is 9 feet of marl resting on clay till. |
| L-4 | Location: | Sec 35, T37N, R4W, in Laporte County, Indiana on 1938 AAA photos BFK 2 (96-97) |
| | Size: | 109 acres |
| | Environment: | Rough morainic topography |
| | Shoulders: | Gradual, well filled shoulders. |

| Site No. | | Analysis and Location |
|---|---|---|
| L-4 (cont.) | Erosion: | Considerable erosion both sheet and gully present. |
| | Predictions: | Size indicates a depth of 32 feet. Gradual shoulders while detracting from this depth are counteracted by the well filled condition of the deposit. Therefore, prediction is 24 feet of muck on clay-marl on granular till at 32 feet. |